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UNION OF SOUTH AFRICA

DEPARTMENT OF COMMERCE AND INDUSTRIES

DIVISION OF FISHERIES

INVESTIGATIONAL REPORT No. 20

OYSTER CULTURE IN SOUTH AFRICA

HYDROGRAPHICAL, BIOLOGICAL AND
OSTREOLOGICAL OBSERVATIONS IN
THE KNYSNA LAGOON, WITH NOTES
ON CONDITIONS IN OTHER SOUTH
AFRICAN WATERS

BY

Dr. P. KORRINGA

(Fisheries Laboratory, Bergen op Zoom, Holland)



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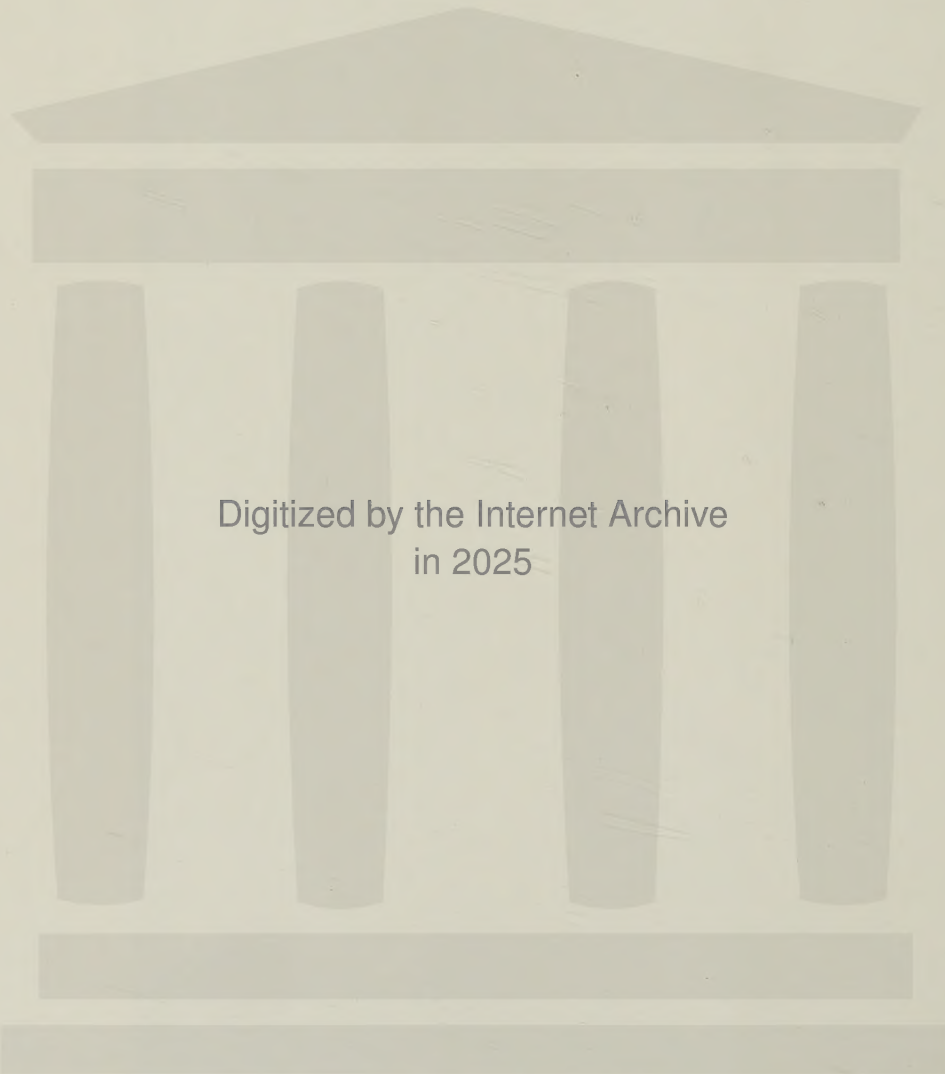
**DEDICATED TO THE MEMORY OF MY DEAR
OLD FRIEND MR. H. G. BRIGHT, THE PIONEER
OF THE OYSTER CULTIVATION AT KNYSNA**

^{*} MS. received 22nd March, 1954.



The Intertidal Zone in South Africa; Typical Conditions.

Photo: A. Blahovsky—Reproduced by courtesy of the Royal Society of South Africa.



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I.—SUMMARY.

To solve the problems met with in the pioneering phase of the oyster cultivation at Knysna, Cape, South Africa, it was necessary to carry out hydrological, biological, and osteological investigations on the spot.

The tides appear to shape the hydrological conditions prevailing in the Knysna Lagoon. Only under exceptional conditions is the run off of the Knysna River of ecological importance for the creatures living inside the lagoon.

From direct observations and analysis of samples of the cold current which sometimes arrives at Knysna in the middle of the summer season, an explanation can be given of the cause and origin of this cold current. The sudden decrease in water temperature which the arrival of the cold current entails is not detrimental to oysters and oyster spat, but it may break off in an untimely fashion the oyster's season of reproduction.

Oyster larvae settling on collectors placed inside the Knysna Lagoon come from parent stocks in the sea. They are carried by the counter-current flowing very close inshore, and are washed into the lagoon with the flood tide. Therefore settling takes place close to the entrance of the lagoon and at about high tide. Biological conditions in the central part of the lagoon, above the railway bridge, are not suitable for oyster larvae, but spat and older oysters may thrive there because of the high food content of the water.

Investigations on the fertility of the waters under consideration demonstrate that particularly the central part of the lagoon is rich in small phytoplanktonic organisms. But even the clear blue water of the inshore counter-current appears to contain enough food for oysters and their larvae. An attempt was made to obtain more insight into the factors governing the fertility of the entire system. Through the agency of bacteria and other microbiota abounding in the central section of the lagoon with its extensive tidal flats and eelgrass fields, the estuary seems to be a kind of trap, as much valuable material washed in from the sea in soluble form is consolidated and accumulated there.

Three species of indigenous oysters appear to occur at Knysna. Of these the common South African oyster, *Crassostrea margaritacea*, an oviparous species, is considered the most promising for oyster cultivation. The small *Ostrea algoensis* should be considered as a "weed-oyster" because of its limited dimensions and slow growth. By means of proper timing of the placing of collectors it is possible to avoid this species settling in appreciable numbers. The red oyster, *Ostrea*

atherstonei, another larviparous species, is very interesting because of its rapid growth and perfect shape. Previously this species was only known from fossil deposits. It occurs at many places along the coast of South Africa, including the West coast, but the numbers settling at Knysna are not of commercial significance, so that it will be extremely difficult to build up a stock of this oyster.

Bottom conditions in the Knysna Lagoon are not inviting for the planting of oysters but other methods of cultivation are possible.

Strong winds stirring up much sand and finer sediment are often inimical, especially for the more delicate types of oyster, like *Ostrea edulis*, the European flat oyster.

The Portuguese oyster, *Crassostrea angulata*, grows and fattens satisfactorily in the Knysna Lagoon and can readily be transported to the Union in the cool chamber of a ship.

Other lagoons and inlets, including Saldanha Bay, are most probably not better suited to oyster cultivation than the Knysna Lagoon.

Oyster enemies do occur at Knysna, but it is as yet possible to cope with them.

Practical recommendations are given for the future development of oyster cultivation at Knysna.

2.—INTRODUCTION.

Since June, 1946, when the late Mr. H. G. Bright came to Holland to discuss the possibility of creating an oyster industry in South African waters, I have given a good deal of thought to this matter. In the first few years it was through the mediation of Mr. Bright that I gave my advice. Later it was mainly through maintaining regular contact with Mr. W. van Dort, the oyster farmer in charge of the experimental work at Knysna, that I co-operated in the venture of the Knysna Oyster Company. The discussions with the late Mr. Bright, the correspondence with Mr. van Dort, and scrutiny of several samples of oysters I received, helped me to build up a fair idea of oyster culture conditions in the Knysna Lagoon, and of the difficulties encountered there.

On the invitation of the Fisheries Development Corporation of South Africa, Ltd., I paid a visit to the Union early in 1953 to investigate and report on the problems of oyster culture on the spot. I worked at Knysna from January 15th to March 7th, 1953, then joined Mr. H. H. Thesen and Mr. W. van Dort on a trip to Saldanha Bay and returned to Cape Town on March 12th, where I completed the analysis of some of the samples collected.

The results of the investigations carried through at Knysna are not only of importance for the future development of the Knysna oyster industry, but may also be considered of interest in relation to enhancement of our knowledge of estuarine biology.

3.—HISTORICAL.

Without doubt it did not take the European settlers of the Cape Colony long to learn that oysters, attached to rocks, are fairly plentiful on some parts of the South African coast. The early settlers were disappointed, however, that such was not the case around the Cape Peninsula and it is known that Governor Isbrand Goske on two occasions between 1673 and 1676 caused some oysters to be brought from the South coast and laid down in Table Bay, with a view to their propagation in a more accessible neighbourhood (Thompson, 1913). Though this venture did not lead to the desired result, viz., the establishment of natural oyster beds in Table Bay several further attempts to acclimatize oysters there were made, mainly in the second half of the 19th century. As it was anticipated that the lagoons at the Salt River mouth quite close to Cape Town, might be suitable for the formation of oyster parks in the French style, spat and mature oysters taken from rocks on the South coast were placed there on several occasions. Every attempt ended in failure, presumably because of prolonged periods of exposure during strong S.E. winds (Thompson, 1913). Lack of basic knowledge of the conditions required by the South Coast oyster for growth, fattening and reproduction was no doubt at the root of the disappointing results.

The same ill-success attended endeavours made in the Eastern Province, where Dr. W. G. Atherstone of Grahamstown had relaid some thousands of Mossel Bay oysters at the mouth of the Kowie River (1882) in the hope that extensive oyster beds would come into being there. The oysters failed to survive, presumably due to freshets and shifting sands (Thompson 1913).

The 1888 "Act to promote the cultivation of oyster fisheries and the discovery of pearl-bearing oysters" in which provision was made for the granting of licenses to form or to plant oyster beds, revived the interest. Though several applications were made, none of the projects led to success. Thompson (1913) states, however, that these ventures were not vigorously prosecuted, but lack of expert knowledge doubtless contributed greatly to the failure.

The Fisheries Commission of 1892 recommended that the services of an expert should be procured, and that the existing indigenous oyster beds should

be improved by introducing the best European varieties. The services of Mr. E. J. Weatherley, who had long been in the employ of the Whitstable Oyster Company, were secured for a year, and he arrived in December, 1893, bringing with him 1,000 Whitstable and 1,000 French oysters. It is not known whether any special measures were taken to keep the oysters cool and alive on board the ship carrying the consignment (Anon., 1894), but as the majority of the oysters died shortly after being placed on trays at the mouth of the Zwartkops River due north of Port Elizabeth, they must have been in poor condition after the long journey. The observation at a later date of fair numbers of young oysters, believed to be the offspring of the introduced oysters, gave hope for a time of success (Thompson, 1913), but as native oysters abound on the rocks at the mouth of the Zwartkops River (Anon., 1894) they might just as well have been young indigenous oysters which had been observed. In any case the Zwartkops experiment was reluctantly abandoned. Freshets, crabs, starfishes, and drills were said to have wrought havoc among the oysters old and young.

Two more consignments of Whitstable oysters came in by ship in the year 1894. They were destined for experiments on the West coast (Saldanha Bay and Berg River), but arrived in too poor a condition to serve the purpose. Four thousand indigenous oysters, collected on the South Coast and relaid in Saldanha Bay promised well at the start. It was even said (Thompson, 1913) that numerous young oysters were found a year after their introduction. Sooner or later all the oysters died, however, due probably to the shifting sand on the bottom.

Thompson (1913) was certainly right in stating that the results of all these experiments were not encouraging; but his conclusion that the South African foreshore is apparently not suited for oyster culture was premature.

It is not surprising, therefore, that after all the discouraging failures at the end of the 19th century, nothing was heard about oyster-culture ventures in South African waters for a long time. Orton (1931), the British oyster expert of the 1920's and 1930's, reviewing the distribution of oysters in the world noted that oyster production on the South African coast appeared to be infinitesimal in comparison with the apparent potentialities. Without having any detailed information on hydrographical and biological conditions or on the occurrence of indigenous oysters at his disposal, Orton surmised that the S.E. coast of Natal would be eminently suitable for spawning and growth of the Portuguese oyster.

He even wondered whether it might have been the cold Benguela Current which had prevented the Portuguese oyster from coming to South Africa all by itself, as if water temperature was the only factor required for settlement of oysters! Orton's suggestion to experiment with Portuguese oysters in Natal waters met with no response.

4.—OYSTER CULTURE AT KNYSNA.

(a) Is Oyster Culture possible in the Knysna Lagoon?

On June 25th, 1946, the late Mr. H. G. Bright, a retired British wine merchant, at that time a citizen of the Union, came to the Fisheries Laboratory at Bergen op Zoom, Holland, to discuss with me whether oyster cultivation would be possible in the Knysna Lagoon. He explained that although he was in Europe for other purposes Dr. S. H. Skaife, at that time Chairman of the Board of Directors of the Fisheries Development Corporation of South Africa, Ltd., had nevertheless suggested to him to collect sufficient information on oyster culture in Europe to find out whether or not the Knysna Lagoon would be suitable for oyster culture. There was a growing demand for oysters in the Union, and the supply of indigenous oysters, locally taken from the rocks at low spring tides was both insufficient and irregular, oyster picking being possible only under exceptional conditions of weather and tide. It was hoped that the total output could be increased considerably through cultivation of oysters, and that the market could be supplied more regularly through adoption of an adequate and reliable storage technique. Though the Fisheries Development Corporation could not reimburse Mr. Bright's travelling expenses, the latter went to work with great enthusiasm and energy, paid several visits to Holland and France, and returned to the Union repeatedly to conduct the first experiments at Knysna, and to report on the information collected in Europe. It seems very doubtful whether experiments on a technically worthwhile scale would ever have been undertaken but for the enthusiasm and drive of Mr. Bright.

(b) Conditions conducive to Oyster Culture.

It is hazardous to state whether or not a certain body of water, thousands of miles away, is suited to oyster culture. Oyster culture has been developed under a variety of conditions in a great number of countries, and in any case the appropriate techniques, adapted to local conditions, are different. Oyster culture is definitely not an industry readily duplicated elsewhere when some of the basic requirements are available.

Experience all over the world demonstrates that the best conditions for developing oyster culture are to be found in estuarine waters with a rather high and constant salinity. The best chances are where old natural oyster beds, depleted or not, are to be found. The bottom should be rather firm with no soft mud or shifting sands. Natural enemies of the oyster should not occur in countless numbers. The water should contain sufficient nutrition for the oyster and its larvae. Summer temperatures should be high enough to induce spawning and to speed up the growth of the oyster larvae. The more the water makes a piston-like movement in the estuary the fewer larvae are washed out to sea by the tidal currents, so that more larvae get a chance to settle down on artificial collectors. Industrial pollution and unhygienic conditions are to be avoided.

It should be clearly understood, however, that these factors do not occur in this combination in every oyster region. In some places it is impossible to grow oysters on the bottom, yet one could develop a remunerative oyster industry (Norway; the Etang de Thau in the South of France; Australia; certain districts of Japan). In other important oyster districts spat collection is insufficient or failing, so that seed-oysters should be imported, often over great distances (e.g. in the Etang de Thau, where Arcachon oysters are grown; in Cornish waters where Brittany oysters are relaid on a commercial scale; and in Willapa Bay in the State of Washington, U.S.A., where Japanese oyster spat is imported on a large scale each year with considerable commercial success).

(c) Spatfall at Knysna.

If spat of indigenous oysters were found to settle in fair numbers on artificial collectors placed in the Knysna Lagoon, there would be every reason for an optimistic view of the possibility of starting an oyster industry there. Oyster larvae may be fairly abundant in certain waters and still find no suitable hard and clean objects (collectors) to settle down on. The number of spat found under natural conditions therefore is not an adequate measure for the potential setting. I suggested therefore that first of all it should be ascertained whether or not larvae of indigenous oysters would settle down on artificial collectors in the Knysna Lagoon. All we knew about reproduction in the S.A. oyster was that Mr. Weatherley (Anon., 1894) found spawning oysters near Port Elizabeth in the month of January. I therefore advised placing small numbers of collectors at intervals of about 14 days at a number of well-selected sites. As we had no information on the existence of natural oyster beds

in the Knysna Lagoon, it was difficult to select the best sites to place the collectors. Some data on water temperatures and salinities in the lagoon, kindly put at our disposal by the S.A. Division of Fisheries, indicated that the area below the Knysna railway bridge might have better hydrographical conditions for the settling of oysters than the area above it. It was very fortunate that Mr. H. H. Thesen of Messrs. Thesen & Co., Ltd., at Knysna was willing to conduct the first experiments on the spot. Both stakes and asbestos roofing tiles were placed as collectors along the rather steep western shore of the downriver section of the lagoon in the summer season of 1946-1947.

In a letter dated June 9th, 1947, Mr. Thesen reported to Mr. Bright that some young oysters had settled on the tiles. Two of the tiles carried as many as 50 young oysters, which at that time were the size of a shilling (see Plate I, Fig. 1). This was certainly a very good result, which brightened the outlook. Though no natural beds of oysters were known to occur within the lagoon, oyster larvae were apparently plentiful enough to settle down on collectors in such numbers as to be of commercial interest, provided the best sites were selected and the collectors were placed in the water at the best time of the year.

Experiments in later years fully confirmed that spatfall of commercial magnitude could be expected to recur every summer on well-selected sites in the Knysna Lagoon (see Plate I, Fig. 2). It can hardly be over-emphasized how necessary it is to have a good spatfall in the water where it is desired to found an oyster industry. If no oyster larvae occurred naturally, it would be necessary to build up an enormous stock of oysters—not just a couple of thousand as some people are inclined to think—before it can be expected that the number of larvae produced in summer would be great enough to lead to a settling of commercial magnitude. Even then it is essential to wait and see whether the local conditions are suitable for the development of the "fastidious" oyster larvae, and whether the tidal currents will not carry away too many.

(d) Does the Oyster grow well at Knysna, and which are its Worst Enemies?

Though the production of young oysters is the first step in oyster culture, it was doubtful whether the oyster could grow and fatten satisfactorily in the waters under consideration. If not, it might be possible to transfer the young oysters produced to areas where growth and fattening were more promising. The first observations on the growth capacities of the indigenous South coast oyster in

in the Knysna Lagoon were not carried out with the spat harvested locally with tile collectors, but with 2,000 half-grown oysters taken from the rocks between the Knysna Heads and Gericke Point, and relaid on a rather flat part of the bottom close to the site where the tiles were placed (September, 1946). It was observed that the oysters, which were of unknown age, did put on significant growth. Some were killed in the summer months through the action of drills (boring gastropods), and in addition a very high percentage were killed off in March, 1947, through the action of the voracious musselcracker [*Sparodon durbanensis* (Castlenau)] (see Plate II). These large fishes of an average weight of 30 lb., have very powerful crushing jaws, equipped with large round or oval molars. They cannot get at the oysters which adhere closely to rocks, but the relaid oysters are easy prey. The meat is eaten and the crushed shells spat out by the fishes. Large shoals of musselcrackers may come into the Knysna Lagoon in March and April. If relaid in very shallow places the oysters have nothing to fear from them, but owing to prolonged exposure their growth is then very poor.

It was concluded from this experiment that there is apparently enough food in the water of the Knysna Lagoon to promote the oyster's growth, but that measures should be taken to protect the oyster against its enemy the musselcracker.

(e) An Experienced Oyster-farmer is charged with the Experimental Work.

Both spatfall and growth of the indigenous oyster being encouraging, it was no more than sensible to explore in greater detail the possibility of establishing an oyster industry in Knysna Lagoon, and to determine whether the indigenous oyster had all the qualities required for remunerative oyster culture. To this end the Knysna Oyster Company, Ltd., was formed, in which the Fisheries Development Corporation and Messrs Thesen & Co. are the shareholders. Mr. Bright declined an offer of 10 per cent of the shares as a reward for his pioneering work, for he wanted to remain an "amateur". Upon my advice the Knysna Oyster Company invoked the assistance of an experienced oyster-farmer in order to explore the possibilities in Knysna Lagoon and to conduct oyster culture experiments on a semi-technical scale. Mr. W. van Dort, an experienced Dutch oyster-farmer, was charged with this work. He arrived in the Union in October, 1948. His first aim was to carry out a series of spat-collecting experiments on a semi-technical scale in order to find out which were the best sites for this work and which was the best

time of the year for placing collectors. To obtain more information on growth and fattening in the local oyster it was planned to select some experimental plots, to fence these in with stakes in order to keep away the musselcrackers, and to place in these enclosures considerable numbers of indigenous oysters taken from the rocks outside the Knysna Lagoon. It was considered wise to collect these oysters at low spring tide only, for oysters from higher levels in the intertidal zone (the so-called "sun-oysters") should be avoided, as these are often stunted and too old for further growth.

(f) Importation of European Oysters.

Pending the results of this work, and too little being known of the aptitude of the indigenous oyster for oyster culture within the Knysna Lagoon, it was considered desirable to introduce a consignment of European oysters for the sake of comparison. The qualities of the European flat oyster (*Ostrea edulis* L.) being precisely known, it could render excellent services as a control for oyster culture in the Knysna Lagoon. Moreover, it would be advantageous to have some experience with European oysters in South African waters in case it was concluded that the indigenous oyster is not a suitable species for oyster culture in the Knysna Lagoon, e.g. because it showed too slow growth, or because of excessive mortality on the oyster plots. I had to stress that, contrary to general expectations, the relaying of imported European oysters in a tidal estuary like the Knysna Lagoon would most probably not lead to the settling of their spat in numbers worth mentioning, unless they were relaid in millions.

To ensure the arrival in good condition of small consignments of European oysters, the best methods of transportation had to be selected. Transportation in the cool chamber of a ship from Holland to the Union takes at least 17 days, which I considered too long for arrival of the young oysters (spat, in prime condition). Therefore transportation by air was preferable. Mr. Bright shipped a consignment of large European oysters (obtained from the Conway Fisheries Experimental Station) by air as early as July, 1946. Unfortunately these oysters were dead on arrival, presumably because of prolonged exposure to high temperatures on tropical air-fields.

To study the possibilities of air transportation I invoked the collaboration of the K.L.M. It was arranged for a thermograph to be placed in the luggage hold of a plane of the Amsterdam-Johannesburg line. From this we learned that during the hours spent in the air, temperatures

in the holds were remarkably even, viz. 18 to 20°C., at which European oysters can be kept alive for many days. However, prolonged sojourns on tropical air-fields made the temperature go up considerably. It was particularly the night spent on the Leopoldville (Congo) air-field which presented serious difficulties in the transportation of living oysters. By reproducing the recorded course of the temperature in the incubator of our laboratory, we could experiment with different insulating and packing materials. It was found that a layer of cork board 2 inches thick, lining the wooden tubs, was sufficient to avoid damage fatal to oysters and oyster spat on the journey from Amsterdam to Johannesburg, provided proper care was taken to keep the tubs cool during the journey from Johannesburg to Knysna. A thick layer of a mixture of sawdust with ice packed around the oyster tubs appeared to work too, but this was inclined to leak, and therefore was prohibited in aircraft. A mixture of sawdust with dry ice made the temperature fall too much (this could kill the oysters) and moreover lost its effect too soon to be useful.

When it was decided to ship oyster spat by air, it was found that the transportation on the route Amsterdam to Johannesburg was quickest. On none of the air-fields on this route did the halt exceed two hours. This greatly reduced the death risk for the young oysters. A simple lining of the wooden tubs or boxes with a thin cork sheeting appeared to be sufficient. All the consignments sent on this air route arrived in perfect condition at Knysna.

(g) Difficulties Encountered.

It was no more than normal that not everything ran smoothly during the experimental phase of the venture at Knysna. Though it may sound paradoxical, it is often the thing that does not develop according to expectation that becomes highly interesting and leads to better knowledge. The variety of difficulties encountered at Knysna was certainly astonishing, and were it not that Mr. van Dort showed all the initiative, perseverance and patience that a pioneer in oyster-culture should possess, the venture might have been abandoned. Fortunately there were always some successful results to offset the reverses, and last but not least there was always the enthusiasm of the Managing Director, Mr. H. H. Thesen, who was determined to guide the venture towards success.

The collection of spat on asbestos roofing tiles was a partial success. Though important natural oyster beds have never been found within the lagoon, fair numbers of oyster spat settled on the

artificial collectors year after year, which made Mr. van Dort presume (in litt. 4/12/1949) that the larvae must come from the ocean. Of the different types of collectors used in the first years, brushwood appeared to collect reasonable numbers of oyster spat, but was liable to serious fouling. Scrap tin, and empty tins nailed on wooden pegs were soon covered with a slimy growth and failed to collect any spat. It is interesting to note that some spat settled on the part of the wooden pegs hidden in the tins, apparently because of the shelter from tidal currents and silting in these sites. Shells, for scattering as collectors, could not be found in large quantities near Knysna, and tidal currents and wave action appeared to be too strong to utilize suspended collectors, e.g. strings of shells or cement-coated cardboard egg-case fillers. Asbestos roofing tiles, coated with a mixture of lime and sand and placed in rows, the one leaning against the other, on strips of scrap wood appeared to be excellent collectors.

Only a small number of tiles was used in the season 1948-49, but unfortunately the spat taken off these tiles and placed in wire-covered trays got lost through the wantonness of too inquisitive visitors. Ten thousand tiles were placed during the summer season 1949-50, and from 25 up to 250 spat were counted on each of these later. Drills did considerable damage but some 150,000 spat were detached. It is understandable that this early success led to the premature calculation of the numbers of marketable oysters to be expected from this spat. The season 1950-51 was characterized by very heavy rains in early summer, which led to reduced salinities and a brown colour of the water in the lagoon. Tiles placed in December became covered with a brown slimy layer and caught no oyster spat, but tiles placed later in the summer caught a fair number of oyster spat.

Generally the spatfall season appeared to range from early December to early March, with a peak from mid-December to the end of January. Following the approved general practice in Europe, Mr. van Dort tried to concentrate on the first part of the spatfall season, in order to have spat as large and resistant as possible at the approach of the colder season. In the season 1951-52 he even managed to place nearly all his tiles before January 1st.

The western shore of the downriver section of the lagoon, especially the place known as Featherbed Bay (see Plate III) appeared to be very suitable for spat collecting operations. Closer to the sea spatfall was equally good, but losses due to drills and starfishes were heavier there. Greenhole, a narrow inlet on the eastern shore, not far from the

sea, was almost equally good for spat collection, but because this was a resort of bathers and campers and because it was very difficult to transport equipment there, all efforts were concentrated on Featherbed Bay.

Growth of the young oysters detached from the tiles gave reason for concern from the very beginning. No place could be found where the young oysters newly detached from the tiles could be scattered without running the risk of being smothered by sand or silt, or being destroyed by predatory fishes. Many efforts were made to grow the spat in trays covered with wire-netting in the hope that they would soon develop a shell large and thick enough to risk planting them on fenced-in plots for further growth and development. From the very beginning difficulties were encountered at this stage. It was impossible to find the required quality of wire-netting (galvanised before and after weaving), so that a wire-netting of lesser durability had to be utilized. It was difficult to protect the wood against the attacks of *Teredo*, as too few trays were available to enable them to be exchanged frequently. It was difficult to protect the trays against wave action during strong winds. Many trays with spat were lost in gales. Inquisitive intruders opened the trays and failed to close them properly. Wave action broke off the shoots of the spat and tossed them in the corners of the trays, where they then found no room to grow. A heavy gale in November, 1951, filled many trays with sand, which killed a great number of oysters. Smothering organisms, among which "red bait", the Ascidian *Pyura stolonifera* (Heller), was the worst, caused the spat to be assembled into unshapely conglomerations and this hindered their growth. Young sea-urchins settled in the trays and nibbled off the new shoots of the shells to obtain calcium for the construction of their own hard shell. Trays placed inside an enclosure in the Slavlei were presumably exposed too long at low tide to favour normal growth.

Still, there was no reason for despair, as some lots of spat showed very promising growth, and spat left undetached for a longer time demonstrated that the indigenous oyster could grow rapidly under favourable conditions. The very irregular results, and the failure of substantial portions of the detached spat to grow normally under apparently suitable conditions gave reason for concern. It turned out later that the spat collected was not homogeneous and consisted of several species of oysters. One of these, unfortunately the most numerous among the spat caught in early summer, appeared to be a very poor grower, and would probably never reach a marketable size.

Planting of oysters on fenced-in plots led to disappointing results. From the very beginning Mr. van Dort worried about the bottom conditions in the Knysna Lagoon. He could not find areas with hard stable bottom suitable for the planting of oysters. Shifting sands and eelgrass fields predominated in the lagoon. In places with little vegetation the mud-shrimp *Upogebia africana* (Ortman), locally called prawn or kapper (see Plate IV, Fig. 1) appeared to be so numerous that sand was perpetually being thrown up in such large quantities that it rapidly smothered the oysters. However, Mr. van Dort decided to make an effort to grow oysters on the bottom, as this undoubtedly is the cheapest method to rear oysters to marketable size. He selected a plot of tidal land in the Slavlei and fenced it in with stakes to keep out the voracious musselcrackers (see Plate IV, Fig. 2). With the idea of making a quick profit, he took over 100,000 medium-sized oysters from the rocks outside the lagoon and planted them in this enclosure. Though they showed rather promising growth shortly after being planted, it was soon evident that they were threatened by smothering sand through the activities of *Upogebia* and through wave-action in rough weather. In addition the so-called seacat (*Octopus vulgaris* Lam.) was always present in fair numbers within the enclosure. It lined its burrows with oysters and evidently killed quite a few. Mr. van Dort did his utmost to keep the oysters out of the sand by repeated dredging with a bagless frame. Too frequent dredging breaks off the new shoots, and finally Mr. van Dort had reluctantly to abandon this enclosure as the oysters disappeared under the sand,

showed poor growth and heavy mortality. It is true that the quality of the relaid oysters was not ideal for experimental work as some were stunted and too old, and had been collected at too high a level in the intertidal zone. Parallel experimentation with the European flat oyster (*Ostrea edulis*) demonstrated, however, that there was little hope of growing oysters directly on the bottom in enclosures in the area below the Knysna railway bridge.

An experimental lot—60 sacks of indigenous oysters—planted in a deeper channel (Wyn gat) was completely destroyed by musselcrackers, evidently within a very short period.

For the sake of comparison, some indigenous oysters and some European oysters (*Ostrea edulis*) were planted in the southern part of Saldanha Bay on the Atlantic coast of the Union, notwithstanding the fact that the bottom appeared to be very sandy here, and that another type of burrowing prawn (*Callianassa kraussi* Stebb.) was numerous there. The results of this small-scale experiment were disappointing; the oysters were smothered in the sand.

Importation of European oysters appeared to be technically possible. The first experimental consignment from Holland was shipped late in April, 1949. To collect information on the dependability of the method of transportation, we made this a varied consignment and shipped one part of it in the cool chamber of a ship, and the other part by plane. Mortality was checked a week after arrival, and again after one month of sojourn in trays in the Knysna Lagoon:—

Type of Oyster.	Method of Transportation.	Total Quantity.	Mortality after 1 Week.	Mortality after 1 Month.
			Percentage.	Percentage.
<i>Ostrea edulis</i> spat, 8 months old. 1 Kg./1,000.....	Plane.....	17 Kg.....	15	20
	Ship.....	Sample....	55	70
<i>Ostrea edulis</i> yearlings (20 months old). 7 Kg./1,000.....	Plane.....	40 Kg.....	4	9
	Ship.....	Sample....	90	100
<i>Ostrea edulis</i> , 2½ years old. 20 Kg./1,000.....	Plane.....	Sample....	15	30
	Ship.....	40 Kg.....	25	60
<i>Ostrea edulis</i> , 3½ years old. 30 Kg./1,000.....	Plane.....	Sample....	15	30
	Ship.....	40 Kg.....	35	70

These results warranted the conclusion that air-transportation of spat and yearling oysters, packed in wooden boxes with a thin lining of cork sheet, might lead to their arrival in perfect condition. The mortality observed should be considered as normal for any transfer of such oysters to other

waters. Shipment in the cool chamber of a ship, requiring about 18 days, led to such heavy losses in these young oysters that nobody would dare to risk shipment of large consignments this way. This was confirmed by a laboratory test in which similar oysters, packed in boxes, were kept for 19 days at a

temperature slightly above freezing point. Few of these oysters survived this treatment. That yearling oysters suffered even more than the spat can be ascribed to the fact that these oysters had already resumed growth before the shipment was prepared, which made them especially vulnerable. Shipment by air of oysters aged $2\frac{1}{2}$ and $3\frac{1}{2}$ years led to reasonably good results, but air-freight was too heavy on such oysters to make shipment of larger consignments an economic proposition. The cost of air-freight per oyster could be reduced by selecting light-weight oysters, either spat or yearlings. The results of transportation by sea of oysters aged $2\frac{1}{2}$ and $3\frac{1}{2}$ years were not encouraging. The losses recorded one month after arrival showed figures which were so high that we considered transportation by sea of large consignments of the European flat oyster too hazardous.

It is customary in Europe to transport and relay oysters in the months of April and May, shortly before the resumption of growth. In shipping oysters to South Africa we realized that they would arrive at the beginning of the colder season, so that they could not resume growth at the usual time. For the oyster this meant two winter seasons in succession, i.e. a greatly prolonged season of restricted activity. For the oyster-farmer it meant prolonged use of expensive trays for oysters which were in a dormant stage for several months, and which might suffer losses in that period. We therefore wondered whether it would not be feasible to ship the young oysters at the end of the European growth season, so that they would arrive in the beginning of the South African summer. Instead of entering a dormant phase, they could resume their growth without delay. The advantages would be clear: there would be no useless months without growth on trays, and the oysters would have an advantage over those of the same year class in Europe in that an entire winter season would be skipped. To test this possibility and to find out simultaneously how the young European oysters reacted to considerable changes of water temperature, we shipped a consignment of Dutch spat by air on January 18th, 1950. They were packed during freezing weather and arrived at the height of the South African summer with water temperature well above 20°C . They arrived in perfect condition and resumed growth shortly afterwards. The losses recorded were negligible. This success led to the shipment of a larger consignment of spat only 4 months old, late in November, 1950. The consignment was made up of 400,000 French spat (Brittany) and 100,000 Dutch spat. These too arrived in perfect condition. In July, 1951, about 85 per cent of these

young oysters were still alive. Late in November, 1951, a further 250,000 recently detached French oyster spat were successfully shipped by air to South Africa. As before, the French oysters were kept for about a week in an oyster basin at Bergen op Zoom before they made the big trip.

Though air transportation of spat, weighing about 1 Kg. per 1,000, appeared to be foolproof, and is per oyster much cheaper than shipment of older and heavier ones, the ultimate results have not been according to expectations. The first small consignments were used for a variety of small-scale experiments, and the young oysters showed excellent growth on trays, both in the Slavlei enclosure and at Featherbed Bay. It was disappointing at that time that no hard non-shifting bottom could be found. Still, some oysters were planted, either with or without a previous sojourn on trays. Through the perpetual activities of the very abundant *Upogebia*, and through sand transportation in rough weather, these planted oysters sooner or later became smothered. However, growth on trays was so good in the first year, that it was considered possible as a commercial undertaking to rear European flat oysters to marketable size in trays. It is understandable that already at this juncture it was estimated at what time and in what numbers oysters could be marketed. Unfortunately growth was considerably poorer in the oysters which arrived later. The weather was then noticeably rougher in summer, which led to tossing about of the oysters in the trays. Again and again the new growth shoots broke off in rough weather. Sand suspended in the water in rough weather might also have exerted a detrimental influence. The gale late in November, 1951, did very serious damage, a high percentage of the trays at Featherbed Bay being filled with sand. As rough weather and high tides persisted for quite some time, the loss of about 80 per cent of the oysters, among which were many of the large consignment of October, 1950, could not be prevented.

As neither the planting of European oysters in the Slavlei enclosure, nor the rearing on trays in Featherbed Bay had led to the results promised by the outcome of the early experiments, Mr. van Dort became reluctant to import further large consignments of European oysters and preferred to experiment on a small scale only. Hence the limited consignment of spat of the European flat oyster shipped late in November, 1951, viz. 250,000.

Among the European oysters imported in November, 1950, Mr. van Dort had found three

specimens which showed considerably better growth than the other oysters. These oysters appeared to be Portuguese oysters (*Crassostrea angulata*), which occur sporadically among the spat of flat oysters detached in Brittany. It is known that Portuguese oysters are a hardier race in many respects, so that it is not surprising that they showed excellent growth under conditions which apparently did not appeal to the flat oyster, *Ostrea edulis*. This observation led to the shipment of a small consignment of Portuguese oysters early in 1952. As Portuguese oysters can stand prolonged exposure, I suggested shipment of part of the consignment by air and part in the cool chamber of a ship, which latter is of course much cheaper. Contrary to common practice some spat was detached at Arcachon (France), and placed on trays, awaiting shipment, late in December, 1951. Unfortunately the terrific gales which hit Western Europe early in January, 1952, destroyed most of this spat, so that only 50 Kg., instead of the planned 200 Kg. of Portuguese spat, could be shipped by air. A sample of 2 Kg. of spat went by sea. In addition we shipped 150 Kg. of yearlings (16 months old) by air and about 25 Kg. by sea. Again, all the oysters spent some days in an oyster basin at Bergen op Zoom prior to further transportation. Those shipped by air arrived in perfect condition and very soon started to grow. Of those shipped by sea the spat suffered a loss of about 60 per cent and the yearlings of about 25 per cent. The survivors grew almost immediately after arrival. We concluded that shipment of yearlings of Portuguese oysters in the cool chamber of a ship is commercially possible, and shipped with considerable success a consignment of 1,200 Kg. of such yearlings in November, 1952. The Portuguese oysters showed excellent growth in the Knysna Lagoon and the losses suffered were negligible. Flat oysters grown under similar conditions showed much poorer results. Though this excellent growth makes it possible to produce first-quality marketable Portuguese oysters after a sojourn of only about 18 months on trays, Mr. van Dort hoped to find a system to cut down the use of trays as far as possible. However, late in 1952 he had not yet found a satisfactory method to grow large numbers of oysters outside the trays.

(h) Problems to be solved.

It was hoped that investigations on the spot would enable me to solve the following problems:—

- (1) What are the wanderings of the oyster larvae in the Knysna Lagoon, and is the Featherbed

Bay area theoretically the best for spat collection?

- (2) Is it true that there is more than one species of indigenous oyster at Knysna, and, if so, what are their qualities for purposes of culture, and how can they be distinguished at an early age?
- (3) If one of the indigenous species is better than the others, what measures can be taken to concentrate on the production of the superior species?
- (4) Is there enough food in the Knysna Lagoon for proper growth and fattening of large numbers of oysters, and, if so, which area is the most promising in this respect?
- (5) Is the bottom suitable for the planting of oysters, either in the Knysna Lagoon or in some other nearby bodies of water?
- (6) When no suitable bottom can be found for the planting of oysters, what other method can be used to grow marketable oysters on a commercial scale?
- (7) Which are the worst enemies of the oyster in the Knysna Lagoon, and which adverse conditions should be avoided?
- (8) What is the reason for the disappointing results with the European flat oyster after the initial success with the first consignment?
- (9) If the Knysna Lagoon is considered unsuitable for the cultivation of oysters, would it be possible to transfer the spat produced there to Saldanha Bay for further growth and fattening?
- (10) What recommendations can be made to promote the oyster industry at Knysna?

5.—HYDROLOGY OF THE KNYSNA LAGOON.

To acquire a good understanding of the local ecological conditions for growth, fattening and survival of oysters, and of the peregrinations of the pelagic oyster larvae, some knowledge of the hydrographical features of the Knysna Lagoon is necessary.

(a) Temperature.

Valuable information on water temperatures has been presented by Day *et al.* (1952). From

series of observations on water temperatures in the surface layer they computed the following averages:—

Station.	Fountain Point.	Brenton and Paarden Island.	Rail Bridge.	The Point.	Westford Bridge.	Old Drift.	Charlesford Rapids.
Distance from the sea in miles.....	0·4	2·6	3·4	6·1	9·7	10·7	11·8
Average summer temperature. °C. (excluding cold current).....	20·8	21·4	22·6	22·1	24·0	24·4	27·7
Average winter temperature. °C.....	15·3	14·9	14·3	15·4	14·3	14·3	12·6

A gradient was observed which is characteristic for conditions in a long estuary. In the upriver section of the estuary with its extensive tidal flats, which greatly facilitate heat exchange, the weather exerts a considerable influence on the temperature of the water. In the downriver section, close to the sea, summer temperatures of the water are lower, and winter temperatures higher than in the upriver area. However, sight must not be lost of the dynamical nature of the temperature pattern: at a given station in the middle part of the lagoon water temperatures may show upriver values at low tide, and downriver values at high tide.

Van Dort's daily temperature readings in the surface layer in the downriver section of the lagoon confirmed the data collected by Day *et al.*, and clearly showed the dynamical pattern mentioned above:—

	High Water.	Low Water.
1949—		
August.....	15·5	15·5
September.....	16·7	16·5
October.....	17·6	18·4
November.....	19·0	19·5
December.....	20·8	21·6
1950—		
January.....	21·3	23·6
February.....	20·4	22·5
March.....	22·2	22·8
April.....	19·5	19·7
May.....	17·8	17·6
June.....	16·1	16·0
July.....	14·7	14·4
August.....	15·1	15·1
September.....	16·8	17·3
October.....	18·7	19·6

Month.	Water Temperature °C. (at Thesen's Wharf).
1948—	
November.....	19·9
December.....	21·9
1949—	
January.....	21·0
February.....	21·0
March.....	19·4
April.....	18·2
May.....	18·2
June.....	16·7
July.....	15·8

In winter, readings at low water tended to be slightly lower than those at high water. In summer, on the other hand, the highest temperatures were recorded at low tide, which is in accordance with Day's figures. In the area below the Knysna railway bridge water temperatures were about 14–15°C. in mid-winter, and about 21–23°C. in mid-summer. Occasional readings recorded by Van Dort in later years, and also the observations I made myself, showed no deviations worth mentioning.

We may therefore conclude tentatively that neither in winter nor in summer do water temperatures reach values which endanger the oyster's life. Winter temperatures will slow down the oyster's activities so that growth may come to a virtual standstill for some time, but it is unlikely that oysters go through a real dormant phase in winter. It is possible, however, that the indigenous oyster reduces its activities at a higher temperature level than do the well-known European and American varieties.

(b) Salinity.

The data on salinities of the surface water in Knysna Lagoon as recorded by Day *et al.* (1952)

show that during both summer and winter the highest values are to be found close to the sea, and that rather low values may be expected in the uppermost section of the lagoon:—

Station.	Fountain Point.	Brenton and Paarden Island.	Rail Bridge.	The Point.	Westford Bridge.	Old Drift.	Charlesford Rapids.
Distance from the sea in miles.....	0.4	2.6	3.4	6.1	9.7	10.7	11.8
Average hightide salinity, ‰.....	35.7	34.8	29.9	33.2	21.7	13.5	7.2
Average lowtide salinity, ‰.....	34.5	31.5	31.3	28.4	16.5	8.8	3.9

This demonstrates that the discharge of fresh water by the Knysna River, augmented by local precipitation, evidently exceeds the evaporation throughout the year.

It is difficult, however, to obtain a good insight into matters by studying observations in surface layers only, for marked stratification may occur, especially in the upriver section of an estuary. The observation of a surface salinity of 4.4‰ while the salinity appeared to be 30.0‰ at the bottom (Day *et al.* p. 374) is certainly significant. A further complication is that here too the real salinity pattern no doubt is of a dynamical nature, it being greatly influenced by the tides.

The data I collected myself during two salinity surveys were very instructive. The first survey (see Plate V) was carried out on the afternoon of January 24th, 1953, from 14.30 to 16.30 hours, and covered the area from the Old Drift to Belvedere Cove. The weather was calm and bright. At Knysna it had been high tide at 11.35 hours and somewhat later higher up in the estuary. The observations therefore hold good for the last part of the ebb tide. The specific gravity of the samples of water collected at different depths was measured with a hydrometer, the water temperature being read simultaneously. From these data the salinities were computed with the aid of Knudsen's tables:—

Station.	Depth.	Specific Gravity.	Temperature.	Salinity.
			°C.	‰
Station I.....	Surface.....	1.0005	26.6	2.0
	30 cm.....	1.0035	26.5	6.2
	50 cm.....	1.0105	26.5	16.3
	65 cm.....	1.0155	26.5	23.0
	80 cm. = 20 cm. above bottom.....	1.0180	26.0	26.2
Station II.....	Surface.....	1.0035	26.5	6.2
	30 cm.....	1.0055	26.0	9.2
	50 cm.....	1.0175	26.0	25.5
	65 cm.....	1.0190	26.0	27.8
	160 cm. = 20 cm. above bottom.....	1.0190	26.0	27.8
Station III.....	Surface.....	1.0060	26.5	9.9
	60 cm.....	1.0100	27.0	16.1
	70 cm.....	1.0130	27.0	19.9
	85 cm.....	1.0170	26.5	25.0
	340 cm. = 20 cm. above bottom.....	1.0190	25.5	27.5
Station IV.....	Surface.....	1.0200	25.5	28.8
	50 cm.....	1.0215	25.5	30.8
	65 cm.....	1.0225	25.5	32.1
	230 cm. = 20 cm. above bottom.....	1.0225	25.5	32.1
Station V.....	Surface.....	1.0235	24.5	33.0
	85 cm.....	1.0235	24.5	33.0
	430 cm. = 20 cm. above bottom.....	1.0235	24.5	33.0
Station VI.....	Surface.....	1.0240	24.5	33.6
	140 cm. = 20 cm. above bottom.....	1.0245	24.0	34.3

These data have been illustrated diagrammatically, see Plate V, which clearly shows a vertical salinity gradient in the upriver section of the estuary. A rather thin layer of water with salinities under $10^0/00$ was observed on top of more saline layers in the area above the new road bridge under construction (Stations I, II, III). Even as far up in the estuary as the Old Drift (Station I) the salinities measured in the deeper water layers appeared to be higher than $25^0/00$. The deeper the water, the thicker the saline layer. We may presume that the thickness of the superficial layer of low salinity will fluctuate to some extent with the run off of the Knysna River, and that the thickness of the saline layers fluctuates with the tide. The incoming flood will creep upriver underneath the brackish layers. At the time of our observations there was a steep gradient about 50 cm. under the surface of the water. The fresher uppermost layers had the brownish colour so characteristic of the rivers coming down from the Outeniqua mountains: the deeper layers, showing no trace of this brown coloration, had a somewhat greenish tint.

In the wider middle section of the estuary, below the new road bridge (Stations IV, V, VI) the vertical salinity gradient had almost vanished.

Wind and tides apparently caused such a thorough mixing in this more open district with its complicated depth pattern, that the salinities in the superficial layers of the water differed only slightly from those in deeper layers. The closer to the sea, i.e. the farther away from the incoming fresh water, the higher the salinities observed.

Though the observations of this first survey were carried out shortly before low tide, the salinities encountered in the middle section of the lagoon should be considered as very suitable for oysters of any type. In the upper section of the lagoon (Stations I, II, III) the salinities in the deeper water layers are high enough for oysters, but the topmost water layers, at that time about 50 cm. thick and moving up and down in a vertical sense with the tide, should be considered as too brackish for oysters.

The second survey (see Plate VI) was made on March 2nd, 1953, in the afternoon from 17:00 to 19:45 hours, and covered the area from the Charlesford Rapids to the wharf at Thesen's Island (Stations I-XII). At Knysna it had been high tide at 16:46 hours, somewhat later higher up in the estuary. In contrast to the first survey this one was carried out at almost high tide:—

Station.	Depth.	Specific Gravity.	Temperature.	Salinity.
			°C.	$^0/00$
Station I.....	Surface.....	0.9995	25.8	0.9
	50 cm.....	1.0010	25.5	2.8
	75 cm.....	1.0040	25.0	6.8
	100 cm.....	1.0080	25.0	12.2
	200 cm. = 20 cm. above bottom.....	1.0100	25.0	15.3
Station II.....	Surface.....	1.0100	26.0	15.6
	350 cm. = 20 cm. above bottom.....	1.0130	24.3	19.0
Station III.....	Surface.....	1.0100	26.0	15.6
	125 cm. = 20 cm. above bottom.....	1.0130	24.9	19.2
Station IV.....	Surface.....	1.0150	24.3	21.6
	250 cm. = 20 cm. above bottom.....	1.0180	24.0	25.5
Station V.....	Surface.....	1.0185	24.0	26.2
	450 cm. = 20 cm. above bottom.....	1.0190	23.8	26.8
Station VI.....	Surface.....	1.0200	23.9	28.1
	350 cm. = 20 cm. above bottom.....	1.0200	23.5	28.0
Station VII.....	Surface.....	1.0225	23.0	31.2
	250 cm. = 20 cm. above bottom.....	1.0225	22.7	31.2
Station VIII....	Surface.....	1.0225	22.8	31.2
Station IX.....	Surface.....	1.0235	22.3	32.3
Station X.....	Surface.....	1.0240	21.6	32.7
Station XI.....	Surface.....	1.0250	20.3	33.4
Station XII.....	Surface.....	1.0250	19.4	33.3

There was a strong south-easter blowing, somewhat deflected by the steep slopes of the river banks in the upper part of the estuary, so that the wind appeared to blow lengthwise in the rather narrow

section between the Westford road bridge and the new road bridge under construction.

A marked stratification appeared to occur in the well-sheltered uppermost section of the estuary

only (Station I). Further downriver the vertical salinity gradient was not very marked, in contrast to the findings on January 24th. The rather thin brackish top layer could not be found. From the Old Drift (Station III) to the Westford road bridge salinities were slightly lower in the uppermost water layers, but farther downriver the differences became almost insignificant. The absence of stratification on March 2nd cannot be ascribed to a smaller run off of the Knysna River as compared with the situation on January 24th. A comparison of the salinities recorded in deeper layers of the upriver section shows that those were even lower on March 2nd at about high tide than on January 24th shortly before low tide. This demonstrates that the run off must have been rather greater than in the period preceding the second survey. I ascribe the absence of a marked stratification to the mixing of water layers by the strong winds blowing on March 2nd and on the days preceding this date.

Though I admit that a greater number of salinity surveys would be very welcome indeed, we may conclude tentatively that in periods of calm weather the run off of the Knysna River will produce a rather thin top layer of low salinity water in the upper section of the Knysna estuary. The deeper layers, however, show a high salinity even as far upriver as the Old Drift. In the wider area below the new road bridge under construction, wind and tide cause such a thorough mixing of the water that marked vertical salinity gradients will rarely be observed there. When strong winds prevail, on the other hand, an obvious stratification of the water can only be found in the well-sheltered upper section of the estuary.

No trace of a vertical salinity gradient was observed by me in the downriver section of the estuary, i.e. below the Knysna railway bridge. Only at times of greatly increased run off of the Knysna River might one expect to find a distinct vertical salinity gradient in the middle section of the estuary, and at low tide even in the downriver area, especially when calm weather prevents a rapid mixing of the water layers.

(c) Tides.

Of considerable importance is some knowledge of the tides in the Knysna Lagoon. According to Day *et al.* (1952), the tidal rise and fall at the entrance of the lagoon is about 6 feet at spring tide. The tidal range is maintained, though with some delay in time, right up to the Westford road bridge

(see Plate VI, Station IV), and diminishes rapidly in the section farther upriver.

However, for studies on the distribution of oyster larvae and on the fertility of the lagoon, it is of importance to know whether or not the water in the lagoon makes a perfect piston-like movement with the tides. There are estuaries (e.g. the Crouch and Roach rivers in Essex, England) in which the water going out at ebb tide returns almost completely with the next flood, which can be described as a perfect piston-like oscillation. In the eastern section of the Oosterschelde (Holland) about 96 per cent of the water moving westward at the ebb returns with the next flood, the remaining 4 per cent being replaced by water of other origin. As a rule the water in funnel-shaped estuaries shows much higher replacement figures. In extreme cases only a little of the water flowing to sea on the ebb returns with the next flood.

Direct observations made during calm and bright weather give some interesting information on the tidal phenomena in the Knysna Lagoon. Looking down from the high eastern Head at the middle of the ebb tide, it can be seen that lagoon water of a somewhat greenish colour pours out into the clear blue sea. Sometimes the lagoon water bends away to the east, at other times to the west, but it certainly does not flow between prolonged sandbars which could prevent its dispersion. At the next flood ocean water pours into the lagoon, but as a rule it is very blue and clear water that enters. This demonstrates that only a low percentage of the lagoon water which flowed into the sea at ebb tide re-enters the lagoon with the next flood. Most probably the degree of dispersion of the lagoon water in the sea depends largely on the strength and direction of the wind, and on wave action, but time did not allow me to study these interesting phenomena in greater detail. While sailing in the lagoon during calm weather it can be observed that the clear blue ocean water follows the deep channels and penetrates far into the lagoon, to beyond the railway bridge. In the shallow parts one may see at the same time a more turbid greenish water, which does not readily mix with the ocean water because it differs somewhat in temperature and salinity. Where the tidal current is less strong the colder and more saline flood water may creep under the greenish lagoon water. During calm weather the very distinct boundary between the two bodies of water can be followed over great distances, especially in the area below the railway bridge.

At the ebb tide there is as a rule not such a marked colour pattern in the lagoon because the

warmer and slightly less saline inshore water of greenish colour tends to flow over the blue ocean water with the outgoing tide. In the main channels a strong tidal current prevails, and this prevents stratification.

To investigate how far the ocean water may penetrate with the flood, and to follow the lagoon water on its way out at the ebb, observations were made with the aid of a drift bottle. In the neck of an ordinary glass bottle of about 1 litre capacity we fixed a thin round stick about 50 cm. long, and topped this with a white painted cork. The bottle was filled with enough water so that only the white cork emerged when the bottle was placed in sea water. In this way the tidal current carried along the bottle, and possible aberrant conditions in the topmost layers caused by wind had little influence on the path the bottle followed. The bottle was followed by boat and at frequent intervals its position was noted down and the time taken. Only if the bottle should strike bottom, should it be taken up and replaced in the middle of the tidal current, but this did not happen during our current observations in the Knysna Lagoon.

The data collected are illustrated in Plates VII and VIII. These data clearly demonstrate that the ocean water coming in with the flood tide penetrates far into the lagoon, following the deep channels. The observations on February 11th showed that it may penetrate well beyond the railway bridge. At the height of the tide the current velocity exceeds 1 nautical mile per hour. The central part of the incoming body of water has no tendency to diverge into the shallow parts of the lagoon. Evidently the deep channels form the bulk of the water capacity in the downriver section of the lagoon. The body of water which we followed on its path with the flood on February 12th did not come straight out of the ocean, but must have been in a position somewhat below the railway bridge at low tide. In the same manner it may be surmised that the flood water in the uppermost section of the lagoon comes from the central area. The capacity of the uppermost section being rather limited, current velocities are much lower in the widening below the new road bridge under construction than for example in the rather narrow section near the railway bridge. We have no exact data on the total capacity of the lagoon nor on the volume of water passing the Heads at each tide, but our general impression from drift bottle surveys and from direct observations is that there is certainly not a perfect piston-like oscillation in the lagoon. The percentage of the water leaving the lagoon on the ebb is without doubt considerable and with the

next flood only a small part of that same water, if any, re-enters the lagoon. The incoming flood does not just push up the lagoon water, but penetrates far into the deeper channels, to well beyond the railway bridge. It is as if the flood runs past the bodies of water in the various inlets, which participate only to a limited extent in the tidal exchange. The section below the railway bridge is filled with clear blue ocean water at high tide, and with rather turbid greenish lagoon water at low tide. The section above the railway bridge has a very considerable capacity. Without doubt some of the water we find here at high tide will leave the lagoon in the last phase of the ebb. Part of this may return with the first flood, but in addition a rather considerable volume of pure ocean water will penetrate here with every tide, more at spring tides than during the neaps.

The entire tidal water renewal is without doubt much greater in the downriver section of the lagoon than in the area above the railroad bridge.

6.—EXCEPTIONAL HYDROGRAPHICAL CONDITIONS.

(a) Floods.

Exceptional conditions may occasionally occur in the lagoon. Heavy rains in the Outeniqua mountains lead to flooding of the Knysna River. Large volumes of brown river water then flow down into the lagoon and can even be followed on their way into the sea at ebb tide. This is a very alarming sight as local fishermen have frequently noticed that such floods may kill sea-cats (*Octopus vulgaris* Lam.) and red-bait (*Pyura stolonifera* Heller) in the upriver section of the lagoon (c.f. Gilchrist, 1914). It is thus only logical that those concerned with the preliminary phases of the oyster venture were very reluctant to consider the area above the Knysna railway bridge as suitable for oyster-culture experiments.

I did not witness this phenomenon myself during my sojourn at Knysna and therefore was not in a position to observe to what extent stratification of the water goes further down in the lagoon than usual during such floods. Mr. van Dort's daily observations at Thesen's wharf enable me, however, to present some data on the effect a heavy run-off of the Knysna River may have on the salinity in that part of the lagoon. Day *et al.* (1952) recorded that the maximum rainfall is to be expected here in

the spring, and accordingly Mr. van Dort observed that in some years—but not every year—the salinity in the surface layers may show a sudden drop in the month of November:—

Date, 1949.	High Slack Water.		Low Slack Water.		Remarks.
	Temperature. °C.	Specific Gravity at that Temperature.	Temperature. °C.	Specific Gravity at that Temperature.	
1 November.....	19.5	1.0265	20.5	1.0260	—
2 November.....	19.5	1.0270	17.0	1.0260	—
3 November.....	19.0	1.0275	16.0	1.0250	NW wind, heavy rain.
4 November.....	19.5	1.0265	20.0	1.0250	—
7 November.....	21.0	1.0260	20.0	1.0250	—
8 November.....	21.5	1.0255	21.0	1.0250	—
9 November.....	20.0	1.0265	20.5	1.0250	—
10 November.....	19.5	1.0265	22.0	1.0240	—
11 November.....	19.0	1.0260	22.0	1.0245	—
14 November.....	19.0	1.0265	22.5	1.0250	—
15 November.....	20.0	1.0275	18.5	1.0270	Rain.
16 November.....	17.0	1.0270	18.0	1.0245	Heavy rain.
17 November.....	15.5	1.0270	17.5	1.0230	Heavy rain.
18 November.....	16.0	1.0270	17.5	1.0135	Run off river water.
91 November.....	—	—	19.0	1.0110	Run off river water.
21 November.....	18.0	1.0270	19.5	1.0170	—
22 November.....	21.0	1.0255	21.5	1.0180	—
23 November.....	21.0	1.0235	20.5	1.0180	—
24 November.....	20.0	1.0245	22.0	1.0200	—
25 November.....	20.0	1.0250	22.5	1.0215	—
28 November.....	19.0	1.0230	21.0	1.0230	—
29 November.....	18.5	1.0240	20.0	1.0235	—
30 November.....	18.0	1.0250	19.0	1.0240	—

These data show that although Van Dort's observations demonstrate that surface salinities at Thesen's wharf fluctuate between 30‰ and 36‰ throughout the year, figures as low as 20‰ and even 15‰ occurred at low tide during a short period of heavy downpour in the month of November, 1949. During this period high-tide salinities remained almost normal, and certainly did not drop to a level dangerous for oysters.

A far more serious flooding was observed by Van Dort in November, 1950, after prolonged heavy rains. Surface salinities at Thesen's wharf dropped one day as low as 3‰ at low tide, but in somewhat deeper water layers salinities did not drop below 14‰ at low tide and 20‰ at high tide. As a rule such low salinities are of short duration only. Although the entire lagoon may show a brown colouration on such occasions, there is every reason to expect that the brackish brown water predominates in the surface layers only, and that large volumes of more saline ocean water penetrate along the bottom of the channels with every flood. The November, 1950, floods were the worst observed by Van Dort since his arrival in September, 1948, but on that occasion

none of his oysters placed in the downriver section of the lagoon was killed by low salinities. If bathed in fresh or very brackish water for several hours a day the oyster just closes its valves and thus escapes injury. The American Atlantic oyster (*Crassostrea virginica*) and some other species of the genus *Crassostrea* can even endure prolonged low salinities. Unfortunately we have no precise information on low salinity tolerance by the indigenous oyster of South Africa, *Crassostrea margaritacea*.

Without doubt salinities in the section above the Knysna railway bridge will show lower values during serious flooding of the river. That purely marine (*stenohaline*) species like sea-cats and red-bait are killed by freshets is no proof that more euryhaline species like flat oysters or the very euryhaline *Crassostrea* oysters cannot survive in the middle section of the lagoon. Our discovery of very large old specimens of *Crassostrea margaritacea* on the piles of the Knysna railway bridge at low water spring level demonstrates that these specimens survived all the floods for at least 10 years. But we even found a large and old specimen of the Cape pearl oyster [*Pinctada capensis* (Sow.)] attached to the piles of this bridge.

This specimen, measuring 13 cm. across, appeared to be in very good condition, and was at that time full of spawn. The pearl oyster certainly is not a euryhaline species, but apparently it easily survived the floods for many years. Much higher up in the lagoon we found on the piles of Grove's Jetty (see Plate III) at low water spring level quite a few old specimens of the flat oyster *Ostrea algoensis* Sow. Flat oysters are considerably less euryhaline than *Crassostrea* oysters. Still the specimens found had been able to eke out their existence for many years in this upriver station; this demonstrates that flood danger is no reason to avoid the section above the Knysna railway bridge in experimenting with oysters in case other conditions might show promising features there. The deeper the level at which the oysters are grown, the smaller the chance that they will be endangered or killed by flooding of the Knysna River. The more euryhaline the type of oyster grown, the smaller the risk. I would not suggest, however, that any experiments with oysters be started in the section above the new road bridge under construction, for it may be expected that low salinities can prevail there for a much longer time than in the middle section of the lagoon.

(b) Cold Water.

Another extreme condition in the Knysna estuary is the cold water that enters the lagoon occasionally in summer. It sometimes happens in mid-summer (January, February) that the temperature of the inshore water drops abruptly to values much lower than those recorded in the winter season, i.e. to a level between 10° and 15°C. This cold water then penetrates far into the lagoon with the flood, to retreat again with the ebb. It mixes imperfectly with the warmer water in the upriver section of the lagoon. As a rule the phenomenon lasts for a few days only, but it may happen that the cold water persists for weeks. According to local residents the cold current appears after a strong south-easterly (onshore) wind has been blowing for several days. Smith (1949) describes how fish are often trapped on the shore and later found numbed in pools; also that the cold water entering the estuary drives the fish before it. Many fishes then seek shelter in the warmer water of the upriver section of the lagoon.

As yet no plausible explanation has been given for the cause of the cold current. General accounts of the oceanographical conditions in the seas around South Africa have been given by Dietrich (1935), Isaac (1937), and Clowes (1950). None of these authors mentions the local inshore occurrence of very cold water in the middle of the summer

season. Most of the data on which they have based their general picture had been collected by oceanographical expeditions, and it so happens that very few of these observations were made in the months of January and February, the time that the cold current may be expected. None of the data concerns the inshore waters in the neighbourhood of Knysna. In his study on the Agulhas current, which sweeps along the East and South coasts of the Union, Dietrich (1935) describes how water temperatures gradually decrease with increasing depth, and how the steepness of the gradient varies with the distance from the coast. If the temperature in the surface layer of the Agulhas current is for example 20°C., the 15°C. layer may be found at a depth of about 350 metres at a distance of 250 Km. from the coast; but in the inshore waters the 15°C. layer can be found at a depth of 100 metres. Similarly the 10°C. level may occur at a depth of 750 metres well offshore and at about 500 metres closer inshore (see Plate IX). This Dietrich calls the phenomenon of dynamical upwelling (dynamischer Auftrieb) as it is caused by differences in velocity within the Agulhas current. Dietrich does not, however, know of a single case in which the colder water breaks through the warmer surface layers at the coast, which would be theoretically possible only when there is very little wind: "Es bleibt offen, ob nicht bei einzelnen Messreihen zur Zeit schwächerer Windströme ein Durchgreifen des dynamischen Auftriebes bis zur Oberfläche festzustellen wäre. Selbst bei ausserordentlich starken Gradienten und dementsprechend starkem dynamischem Auftrieb, vermag ein verhältnissmässig schwacher Triftstrom, wenn er, wie in diesem Falle an der südafrikanischen Küste, quer zum Gradientenstrom läuft, die Auftriebserscheinung an der Oberfläche vollkommen auszulöschen".

Considering that the cold current always arrives after prolonged strong south-easterly winds, which is fully confirmed by the information given earlier by Gilchrist (1914), it seems highly improbable that the phenomenon of dynamical upwelling, as described by Dietrich, has anything to do with it.

I was fortunate enough to witness the cold current myself, and can adduce interesting information which may throw more light on the cause of this phenomenon. During the third decade of January and the first and second decades of February, 1953, we invariably recorded in the incoming flood water temperatures between 22° and 24°C. Then suddenly after several days of strong S.E. winds we measured on February 23rd a temperature as low as 15°C. Local residents who had been fishing on the coast on Sunday,

February 22nd, told me that the coastal water was unusually cold. In contrast to the general pattern, the cold water lasted longer than just several days. The temperature of the incoming flood water rose gradually to 17° and 18°C. on February 26th and 27th, but on March 3rd we measured a temperature as low as 13°C. Fairly strong S.E. winds kept blowing. I was informed by Van Dort that it took until the middle of March before normal temperature conditions were restored. Since his arrival in S.A. in 1948 he had never witnessed a cold current of such exceptionally long duration.

The strong S.E. winds which accompanied the phenomenon certainly make it impossible to give an explanation in terms of dynamical upwelling. The regular upwelling water which we find for instance along the west coast of South Africa requires a prevailing *offshore* wind. The cold current at Knysna, however, which is invariably associated with strong S.E. winds, cannot possibly be explained in similar terms. The very sudden appearance and disappearance of the cold water preclude that air temperatures have anything to do with the phenomenon. Evidently the usual Agulhas surface water is temporarily replaced by the cold water.

This is fully confirmed by closer observations. Plankton samples taken in the incoming cold flood water revealed that the quality of the plankton had changed overnight. For several weeks I had examined plankton samples taken in the warmer inshore water, which appeared to be poor in diatoms, but rather rich in a variety of larvae of benthic invertebrates such as lamellibranchs, gastropods, barnacles, echinoderms, etc., and also contained a fair number of copepods. The samples taken in the cold water on February 23rd, and also the samples taken in the flood water during the following days, revealed a very different plankton. It was a rich plankton in which the phytoplankton component predominated. *Noctiluca* was superabundant on February 23rd, but there were also many dinoflagellates of the type *Ceratium*, together with a great number of diatoms; and on several occasions I found a red *Peridinium*-like creature. In this respect it is interesting to note that local residents claim that they saw in that period red patches in the sea, some of which came into the Knysna Lagoon with the flood. Evidently a case of "red tide" caused by dinoflagellate concentrations. I further observed several radiolarians in the plankton samples collected in the cold water. The invertebrate larvae had disappeared completely, but copepods, though of quite a different type from those found in the warm water, were abundant.

It was as if the warm neritic water with its great number of larvae of benthic invertebrates had suddenly been replaced by colder water of a purely oceanic character, rich in phytoplankton, but devoid of invertebrate larvae. This tallies very well with our earlier conclusion that it cannot have been the dynamical upwelling which brought the water in, for the rich and thriving phytoplankton, the sudden disappearance of larvae of bottom invertebrates and the abundance of an organism like *Noctiluca*, which always tends to rise to the surface, make it highly improbable that the cold water had come from the dark depths of well over 100 m. below the surface.

I found these changes in character of the plankton so striking and interesting, that I invoked the assistance of two specialists to elaborate the copepod and diatom components of some samples I had preserved for the purpose. Dr. W. Vervoort of the Leyden University was kind enough to identify the copepods and Mr. A. van der Werff of Abcoude (Holland) studied the diatoms. The results obtained are listed in Table I.

Both Dr. Vervoort and Mr. van der Werff concluded that the samples collected prior to February 22nd, 1953, clearly showed the character of a neritic plankton, with many species typical of the Indian Ocean. This is according to our anticipation, for these samples had been collected either inside the Knysna Lagoon or close inshore in the countercurrent, which sweeps along the coast and thus collects its invertebrate larvae and other organisms typical of the neritic habitat. The samples collected on February 23rd and during the other days of cold water showed a very different character. Both the copepods and the diatoms found in these samples are of a truly pelagic and oceanic nature. This fully confirms our impression that the rather warm neritic water had been replaced by colder truly oceanic water.

It is further noteworthy that the colour of the cold water is definitely more grey than the very blue Agulhas water. This makes it possible to observe its arrival directly. Mr. Ben, the pilot at Knysna, assured me that he repeatedly witnessed the arrival of the cold water after prolonged strong south-easterly winds, in the months of January and February. Sometimes it just drives straight inshore, at other times it appears first of all as a narrow band along the coastline (c.f. Gilchrist, 1914), which band broadens gradually when the wind keeps blowing, until the greyish colour prevails as far as one can see. It is then as if the cold water dives under the lighter warmer layers and finally lifts these up to drive them away.

TABLE I.

	Plankton Samples.										
	Neritic Water of Counter-current.						Cold Current—arrived 22/2/1953.				
Species.	Thesen's Wharf, Knysna Lagoon, 2 m., 100 l. 110 μ meshes, 1 hr. ebb, 23/1/1953.	The Heads, Knysna Lagoon, tow net 100 μ meshes, H.W., 23/1/1953.	Thesen's Wharf, Knysna Lagoon, tow net 110 μ meshes, half ebb, 10/2/1953.	Thesen's Wharf, Knysna Lagoon, tow net 70 μ meshes, half ebb, 10/2/1953.	2½ miles offshore Knysna Heads, tow net 110 μ meshes, flood, 18/2/1953.	The Heads, Knysna Lagoon, tow net 110 μ meshes, H.W., 18/2/1953.	The Heads, Knysna Lagoon, 2 m., 100 l. net 110 μ meshes, H.W., 23/2/1953.	The Heads, Knysna Lagoon, tow net 110 μ meshes, H.W., 23/2/1953.	The Heads, Knysna Lagoon, tow net 70 μ meshes, H.W., 24/2/1953.	The Heads, Knysna Lagoon, 2 m., 100 l. net 110 μ meshes, H.W., 24/2/1953.	Featherbed Bay, Knysna Lagoon, 2 m., 100 l. net 110 μ meshes, H.W., 3/3/1953.
Copepods—											
<i>Clausocalanus furcatus</i> (Br.).....	—	—	—	—	—	x	—	—	—	—	—
<i>Corycaeus tenuis</i> Giesbr.....	—	—	—	—	—	—	—	—	—	—	—
<i>Euterpina acutifrons</i> (Dana).....	—	—	—	—	—	—	—	—	—	—	—
N. <i>Harpacticus gracilis</i> Cl.....	—	—	XX	XX	XX	XX	x	—	—	—	—
O. <i>Microsetella rosea</i> Dana.....	—	—	—	—	—	—	—	—	—	—	—
N. <i>Oithona nana</i> Giesbr.....	XXX	XXX	XXX	XXX	XXX	XXX	—	—	—	—	—
O. <i>Oithona oculata</i> Farran.....	—	—	—	—	—	—	—	—	—	—	—
O. <i>Oncaea subtilis</i> Giesbr.....	—	—	—	—	—	—	XXX	XXX	—	XX	—
N. <i>Paracalanus parvus</i> (Cl.).....	—	x	—	—	XXX	XX	—	XX	—	—	—
Diatoms—											
<i>Achnanthes longipes</i> Ag.....	—	XX	x	—	—	—	—	—	—	—	x
a. <i>Actinocyclus ehrenbergi</i> Ralfs.....	—	—	—	—	—	—	—	x	—	—	—
a. <i>Actinocyclus undulatus</i> Ralfs.....	—	—	—	—	—	—	—	x	x	—	XX
a. <i>Amphora ovalis</i> Kütz.....	—	x	x	—	—	—	—	—	—	—	—
a. <i>Bacillaria paradoxa</i> Gmelin.....	—	—	XX	XX	x	x	—	—	—	x	—
a. <i>Bacteriasterum</i> sp.....	—	x	—	—	—	—	—	x	—	—	—
a. <i>Biddulphia pulchella</i> Gray.....	—	—	—	—	—	—	—	x	x	—	x
a. <i>Biddulphia regia</i> (Schultze) Ostf.....	—	—	—	—	—	—	—	x	x	—	XX
a. <i>Chaetoceros</i> sp.....	—	—	—	—	—	—	—	x	—	—	—
a. <i>Climacosphemia monilifera</i> Ehr.....	—	x	—	—	—	x	—	x	—	—	—
a. <i>Cocconeis scutellum</i> Ehr.....	—	x	—	—	—	x	—	x	x	x	—
a. <i>Cocconeis</i> sp.....	—	—	—	—	—	—	—	—	—	XX	x
a. <i>Coscinodiscus excentricus</i> Ehr.....	x	x	—	—	—	—	—	x	x	x	XX
a. <i>Coscinodiscus marginatus</i> Ehr.....	—	—	—	—	—	—	x	XX	XXX	XX	XXX
a. <i>Coscinodiscus nitidus</i> Greg.....	—	—	—	—	—	—	—	x	—	—	—
a. <i>Coscinodiscus nodulifer</i> A. S.....	—	—	—	—	—	—	—	x	x	—	—
a. <i>Coscinodiscus radiatus</i> Ehr.....	x	—	—	—	—	—	—	x	x	—	XX
a. <i>Coscinodiscus stellaris</i> Roper.....	—	—	—	—	—	—	—	x	—	—	XXX
a. <i>Grammatophora angulosa</i> Ehr.....	—	—	—	—	—	—	—	—	—	x	—
a. <i>Grammatophora marina</i> Kütz.....	x	x	—	x	—	—	—	x	—	—	—
a. <i>Isthmia enervi</i> Ehr.....	—	x	XX	—	—	—	—	x	x	—	—
a. <i>Licmophora</i> (type <i>flabellata</i> Ag.).....	x	XXX	x	x	—	x	—	—	—	—	—
a. <i>Licmophora</i> (type <i>paradoxa</i> Ag.).....	—	x	—	—	—	—	—	—	—	—	—
a. <i>Mastogloia bonoiata</i> (Grun.) Cl.....	—	—	—	—	—	—	—	—	—	—	—
a. <i>Melosira sulcata</i> (Ehr.) Kütz.....	—	—	—	—	x	—	—	x	x	—	x
a. <i>Melosira</i> sp.....	—	x	x	—	—	—	—	—	—	—	—
a. <i>Nitzschia sigma</i> (Kütz) W. Sm.....	—	XX	—	—	—	—	—	—	—	—	—
a. <i>Planktoniella sol</i> (Wall) Schütt.....	x	XX	—	—	—	—	x	XXX	XX	x	XXX
a. <i>Pleurosigma</i> (type <i>aestuarii</i> W. Sm.).....	—	x	—	—	—	—	—	—	—	—	—
a. <i>Rhizosolenia alata</i> Brightw.....	—	—	—	—	—	—	—	XX	x	—	x
a. <i>Rhoicosphenia curvata</i> (Kütz) Grun.....	—	—	—	—	—	—	—	x	x	—	—
a. <i>Stephanopyxis turris</i> Ralfs.....	—	—	—	—	—	—	—	x	—	—	—
a. <i>Striatella unipunctata</i> (Lyngb.) Ag.....	—	—	x	—	—	—	—	—	—	—	x
a. <i>Synedra</i> sp.....	—	XX	—	—	—	—	—	—	—	—	x
a. <i>Thalassiothrix longissima</i> Cl. and Grun.....	—	XX	—	—	—	—	—	XX	x	—	—
a. <i>Thalassionema</i> sp.....	—	—	—	—	—	—	—	—	—	—	—
a. <i>Triceratium favus</i> Ehr.....	—	—	x	—	—	—	—	x	—	—	—
INSERTAE SEDIS:											
<i>Spermagotonia antiqua</i> Leud. Fortm.....	—	—	—	—	—	—	—	XXXX	XXX	XX	x
SILICOFLAGELLATA:											
<i>Dictyocha fibula</i> Ehr.....	—	—	—	—	—	—	—	XX	XX	x	x
<i>Distephanus speculum</i> (Ehr.) Haeck..	—	—	—	—	—	—	—	x	—	x	x

NOTES:—

N — Neritic species.
 x — present, but rare.
 XX — present in fair numbers.

O — Oceanic species.
 XXX — abundant.

a — Mentioned in Antarctic literature.
 XXXX — superabundant.

Basing my ideas on the observations and data given above, I offer the following explanation for the origin of the cold water:—

The Cold Water, which sometimes makes its appearance at Knysna in mid-summer after prolonged south-easterly winds, which may have reached gale force well off-shore, is Surface Water originating from South of the Sub-tropical Convergence.

From Chart No. 4 in Clowes' 1950 paper we can derive that surface water with temperatures of about 10°C. is to be found south of the sub-tropical convergence south-east of Knysna at about 42° S. i.e. roughly 900 Km. (500 sea miles) away. Dietrich (1935) stated that the wind may have a very considerable influence in this area: "Dagegen ist am Südrand des Agulhasstromes wie im ganzen Untersuchungsgebiet der Triftstrom das beherrschende Element. Einige Beobachtungen lassen erkennen, dass zweifellos tiefreichende Störungen im Stromsystem auftreten können". It is therefore logical to assume that the cold water arriving at Knysna is blown inshore by strong south-easterly winds from beyond the nearby subtropical convergence. Hence the truly pelagic nature of its plankton, and hence the occasional occurrence of cold water fishes like the snoek on Africa's South coast, sometimes as far east as Port Elizabeth (Gilchrist, 1914).

The phenomenon certainly is not limited to the Knysna area. A local resident of Durban told me that strong south-easterly winds may in January or February suddenly but temporarily bring in cold water on the Natal coast. We hope that additional oceanographical observations will some day be made offshore in the area under consideration during the arrival of the cold water in order to corroborate whether or not my explanation is correct.

The question arises whether the phenomenon of cold water could endanger the oyster venture at Knysna. Laboratory experiments I carried out in Holland with the European flat oyster (*Ostrea edulis* L.) demonstrated that this oyster does not suffer perceptibly from sudden changes in temperature, e.g. from 25° to 2°C. and conversely. Even oyster larvae can stand this without apparent damage. During the prevalence of the cold water at Knysna I kept oysters of several types under observation in the oyster basin which receives a regular supply of water from a depth of 4 m. at Thesen's wharf. These oysters were bathed in water of 13° to 15°C. at high tide and in water of well over 20°C. at low tide. At most, part of them closed their valves when the cold water came in,

but none of these oysters died during the cold water period. Featherbed Bay (see Plate III) was the site where the tile collectors were placed. Many young oysters (*Crassostrea margaritacea*) settled on these tiles in the third decade of January, 1953, and therefore were still very small when the cold water came in. No unusual mortality could be observed after weeks of daily abrupt temperature changes late in February and early in March, 1953. In previous years Van Dort observed no mortality after short periods of cold water.

The cold water may, however, be detrimental when it arrives at the time during which the oyster larvae are still pelagic. As the cold water drives away the warm water containing the oyster larvae in various developmental stages, the oyster larvae disappear overnight, and a very good potential spatfall may suddenly be destroyed. If the cold water stays for a few days only there is a remote chance that the warm water with the oyster larvae may return later, but in the case of a prolonged cold spell, similar to the one I witnessed in February and March, 1953, the spatfall comes to a sudden end.

7.—THE FERTILITY OF THE KNYSNA LAGOON.

(a) Methods.

Though it should be considered as a basic requirement in oyster cultivation that enough food should be available to ensure rapid growth and fattening, a hundred years of oyster culture has not yet led to the development of a reliable method of assessing the quantity of oyster food in a given body of water. It is even difficult to say what exactly constitutes the oyster's food. The oyster filters off the water with its intricate gill apparatus, during which procedure it makes ample use of mucus to catch and envelop minute food particles. Though the oyster is able to recognize and reject objects and organisms inimical to it, it ingests along with its true food a considerable volume of inert material such as indigestible silt particles. Most of the larger planktonic organisms are not digested by oysters and leave their intestinal tracts unchanged, often alive, though badly entangled in sticky mucus. It is generally accepted that little, if any, of the zooplanktonic organisms are digested during the rapid passage through the oyster's alimentary tract, and also that most, if not all, of the larger diatoms are found alive in oyster faeces. Very small diatoms, and also small unarmoured flagellates, as well as minute particles of organic

detritus are said to constitute the oyster's main diet, but it seems also possible that at least some of the larger diatoms are crushed against the oyster's gastric shield, and also that organic particles too minute to see under the microscope are caught and digested. However this may be, the oyster should be considered as mainly herbivorous.

It is unfortunately impossible to draw any conclusions on the food content of the water by studying plankton samples collected with an ordinary plankton net made of bolting silk, for the smaller organisms, including the smallest diatoms and the unarmoured flagellates, escape through its meshes. Even centrifuging is not a foolproof method, for many small flagellates either burst during the procedure, or are not sufficiently heavy to become concentrated, while the smallest particles escape our attention anyhow. There is an approved practical method of checking whether or not there is enough food in the water for oysters, viz. the empirical method of planting oysters in the body of water under consideration. Again, this method is not foolproof, for factors other than food may interfere, and nothing will thus be learned about the number of oysters the given body of water will be able to support. This method also has the drawback that one may spend several seasons of experimenting before a clear picture emerges.

Though we admit frankly that it is still very difficult to give an exact figure for the quantity of oyster-food, we can draw valuable conclusions from a combination of data related to the water's fertility:—

- (1) Though as a rule the inorganic nitrate and phosphate content are considered as basically important indicators of water fertility, and especially the latter as a possible limiting factor or bottle-neck, I am of the opinion that these values may easily lead to false conclusions when superficial layers of shallow water are examined, since the phytoplankton assimilates both the phosphates and the nitrates very readily wherever sufficient sunlight is available. Therefore low phosphate figures do not necessarily indicate a low fertility of the water. For a sound comparison it is much better to incorporate in the analysis the phosphorus assimilated by the plankton and then to present the results in terms of organic phosphorus compounds in the phytoplanktonic organisms and their excreta and remains, or in terms of animal protein in zooplanktonic organisms and their remains. Since Harvey (1948) developed a good method of converting all organic

phosphorus in sea water samples into phosphates, it is possible to make total phosphorus estimations in which both the original dissolved inorganic phosphates and the phosphates produced by destruction of the organic phosphorus (present in living organisms, in detritus particles, and in truly dissolved or colloidal organic matter) are added up. Since fishes and other organisms constituting similar big concentrations of phosphorus escape our sampling, the final figures are to be considered as minimum values to be accepted with reservations.

The method adapted from Harvey can be described concisely as follows:— Before a sample is drawn from the large carboy in which the water was carried to the field laboratory, it is necessary to shake it vigorously to restore the homogeneity of the water, for diatoms and silt particles settle very readily on the bottom of the carboy. A sample of 200 cc. is drawn into a very clean glass bottle, and 1 cc. of a freshly-made aluminium-hydroxide precipitate is added. This provides the marine bacteria with ample solid surface so that they develop primarily on this precipitate and in much smaller numbers on the glass walls of the bottles. These samples, kept in the dark, can be analysed later, provided all bacteria developed on the hydroxide are included in the analysis.

The samples collected during the investigations at Knysna were analysed by Dr. A. J. Clowes and Mr. A. C. Paterson, staff members of the Division of Fisheries at Sea Point, Cape Town. To 70 cc. of each homogenised sample 4 drops of saturated Na_2SO_3 solution and 1 cc. of 50 per cent by volume concentrated sulphuric acid were added. These samples were next cooked for 5 hours at a gauge pressure of 15–20 lb. per square inch, and after cooking were ready for the regular phosphate analysis with the molybdate reagent:— 1 drop of SnCl_2 solution (0.1 g. Sn. dissolved in 2 cc. concentrated HCl, then made up to 10 cc. with distilled water) and 2 cc. of ammonium molybdate solution (6.6 g. ammonium molybdate and 6 cc. concentrated sulphuric acid in 400 cc. distilled water) were added; after 10 minutes the blue colour was compared with that of a standard solution with the aid of a colorimeter. The standard solution (made up by dissolving a known quantity of KH_2PO_4 in a 3 per cent solution of NaCl to avoid a salt error) contained 0.5 mg. atom P. per m^3 .

- (2) Apart from a general impression of the total phosphorus content of the water samples, I chose to use a pigment analysis as a second criterion for their fertility. The phytoplankton contains several pigments, among which chlorophyll and several yellow substances are the more important. It is a much easier procedure to obtain an impression of the total quantity of phytoplankton organisms by extracting and measuring these pigments than by enumerating all the phytoplankton organisms, which are of a very different shape and size, under a microscope. It is true, some partly decomposed minute fragments of eelgrass-leaves and the like may become included in pigment analysis, but as these most probably do constitute part of the oyster's diet, it is preferable to include rather than exclude this material. In the pigment analysis, adapted from various authors, known volumes of well homogenated water (as a rule 1, 2 or 3 litres) were drawn by suction through a non-pigmented filtering sheet. At the time I worked at Knysna I used paper filters of various pore size, i.e. "Delta" filters Nos. 365, 366 and sometimes also No. 368, which are of decreasing pore-size and therefore can give an impression of the relative importance of larger and smaller pigment-bearing organisms and particles. The filters bearing the plankton and inert sediment were held above boiling water for about 15 seconds to destroy the chlorophyllase, and next were put in small glass vials under 8 cc. of methyl alcohol to extract the pigments. If the vials are kept in darkness ultimate analysis may be carried out at a later date. In our particular case analysis was carried out in the Cape Town laboratory of the Fishing Industry Research Institute, where I was kindly assisted by Dr. J. S. Willmer of its staff. First of all the pigment extracts were carefully freed from sediment and paper fibres which might influence the readings. We used a microfilter of sintered glass (Baird and Tatlock No. K. 754 H. 4) which yielded a completely clear fluid. This was next made up to exactly 10 cc. and then measured with a Beckman spectrophotometer (type DU with 1 cm. cells) in the wave lengths 430 $m\mu$ and 670 $m\mu$. The standard used was a solution of 25 mg. potassium chromate and 430 mg. nickel sulphate made up to 1 litre with distilled water. The data were computed per litre of sea-water, reduced to readings of the standard, and serve very well for a general comparison.
- (3) As a third criterion I used a measure for the quantity of organic matter in sea-water. For a correct chemical analysis of all the organic matter present in a sample of sea water the best system is a wet combustion with a mixture of chromic acid, phosphoric acid and sulphuric acid as oxidizing agents. The resulting CO_2 should then be determined by weighing in ascarite tubes or by back-titration of HCl solution of known normality. This method cannot be practised in a small field laboratory similar to the one which I had at my disposal at Knysna. Moreover, it is not so much the total quantity of all organic matter in sea-water which interests us, but especially the biologically oxidizable organic matter, which can either be utilized and mineralized by bacteria, or, without previous transformation, be used as food by filter feeders and the like. To estimate the biologically oxidizable organic matter one can either determine the biochemical oxygen consumption after storage for a given number of days at a given temperature, or use the permanganate test. The latter method, lending itself very well to work in a field laboratory, was used at Knysna. For sea-water, with its high salt content, a modification of the original Schulze-Trommsdorff prescription was used. The water should be analysed shortly after sampling to avoid changes due to bacterial activity. The larger the carboy in which the water is temporarily stored, the slower the changes, owing to the effect of solid surface as described by ZoBell (1943). If analysis within 24 hours is impossible, the samples can be preserved by adding 100 mg. corrosive sublimate per litre. After thorough homogenation 100 cc. aliquots are brought to the boil; then precisely 10 cc. of 0.01 N alkaline potassium permanganate (316 mg. $KMnO_4$ and 16 g. NaOH made up to 1 litre with very pure glass-distilled water) is added. The samples are now gently boiled for exactly ten minutes after which the reaction is ended by rapidly cooling the flasks under running cold water. Next 10 cc. 4 N H_2SO_4 is added, and after swirling, 0.5 g. KI dissolved in 5 cc. distilled water, after which the freed iodine is titrated with 0.01 N thiosulphate, using soluble starch as an indicator. All the readily oxidizable organic matter—just that which is biologically interesting—is turned into CO_2 and H_2O by the permanganate. The longer the boiling is continued the higher the percentage of organic matter destroyed, but for

convenient practical use boiling for 10 minutes is generally accepted as satisfactory, even though one may not assume that all organic matter is thus oxidized. It is very important to exercise meticulous care in this work and to use very clean glassware and very pure distilled water. Also one should be very careful to cool the preparation first and next add the sulphuric acid instead of adding the sulphuric acid first as is often prescribed (e.g. in the widely-used booklet of Meerburg and Massink, 1934), which leads to development of some free chlorine and uptake of extra permanganate.

The results are expressed as mg. permanganate required per litre of sea-water, and not in mg. organic matter. There is usually a variety of organic compounds in sea-water—both in particulate form and in colloidal state or true solution—and these varieties require varying quantities of oxygen for their complete combustion. According to ZoBell (in lit.) complex lipids and nitrogenous compounds predominate in the open sea, exclusive of the particulate matter. One can, however, approximate the quantity of organic carbon oxidized, for on an average 1 mg. of KMnO_4 combusts about 0.20 mg. organic carbon. This corresponds very well with the results obtained by the biochemical oxygen demand method in which 1.0 mg. of oxygen is utilized in the oxidation of approximately 1.0 mg. of organic carbon (ZoBell, in lit.).

For the sake of comparison it may be interesting to note that the water of the Oosterschelde, the

oyster district in Holland, usually requires 6 to 7 mg. KMnO_4 per litre, but only about 1 mg. of this amount is used to oxidize the larger plankton organisms and detritus particles, further about 0.6 to 0.7 mg. for bacteria, very small flagellates and other minute particulate matter which can be filtered off with a Berkefield candle. By far the greatest percentage of the organic matter does, however, pass a Berkefield filter, and therefore is either truly dissolved or in colloidal or similar finely-dispersed form.

(b) Observations.

I used these three methods of analysis, either separately or in combination, to obtain an impression of the fertility of the Knysna waters. Our samples can be divided into the following groups:—

- (i) Warm inshore ocean water, sampled before February 22nd;
- (ii) cold inshore ocean water, sampled after February 22nd;
- (iii) water from the middle section of the lagoon;
- (iv) fresh water in the Knysna River; and
- (v) miscellaneous samples from other lagoons, lakes and inlets tested in a preliminary way for their properties as prospective oyster waters.

(i) Samples of the warm inshore water were collected near the Knysna Heads at high tide on February 9th, and also about 2½ miles offshore from the Knysna Heads (with the kind assistance of Mr. Ben, the pilot at Knysna) on February 17th, and 18th. Two small samples were collected at Walker Point (see Plate X), on February 15th:—

Station.	Knysna Heads: Black Buoy.	2½ Miles Offshore Knysna Heads.	2½ Miles Offshore Knysna Heads.	Walker Point. Clear Open Rock Pool.	Walker Point. Spray-filled Pool.
Date.....	9/2/1953.	17/2/1953.	18/2/1953.	15/2/1953.	15/2/1953.
Tide.....	H.W.	4 hr. flood.	5 hr. flood.	L.W.	L.W.
Temperature.....	21.6°C.	—	23.6°C.	—	—
Salinity.....	35.0‰	33.8‰	—	33.6‰	33.2‰
P. mg. atom/m ³	0.31	0.23	0.37	0.39	0.31
Pigment/1: (standard 1.0).....	430mμ 670mμ	—	430mμ 670mμ	—	—
Filter 365.....	0.42 1.8	—	0.48 2.4	—	—
Filter 366.....	0.90 4.0	—	0.52 2.6	—	—
Filter 368.....	0.90 4.2	—	0.80 4.0	—	—
Organic matter mg. KMnO_4 /l.	6.5	7.0	6.6	8.3	10.4

Though we expected to find very low fertility in the clear blue ocean water, there is apparently a fair amount of total phosphorus, and a quantity of readily oxidizable organic matter about equal to

that commonly found in the highly-fertile Oosterschelde. The plankton is not very poor, but microscopical observations showed that animal forms predominate. This is not surprising, since phytoplankton is continually being grazed down by the zooplankton organisms in such warm water with equable ecological conditions. From the

pigment readings it may be concluded that the smaller phytoplankton organisms, withheld by the densest filters used, contribute a fair percentage of the bulk.

(ii) It is very interesting to compare samples of the cold ocean water, collected after February 22nd:—

Station.	Knysna Heads: Black Buoy.	Thesen's Jetty: 50 m. offshore.
Date.....	23/2/1953	3/3/1953
Tide.....	H.W.	Half ebb.
Temperature.....	15 0°C.	—
Salinity.....	33.50/00	—
P. mg. atom/m ³	0.70	0.70
Pigment/l: (standard 1.0).....	430m μ 670m μ	430m μ 670m μ
Filter 365.....	1.25 5.6	1.00 2.6
Filter 366.....	— —	1.40 3.4
Filter 368.....	— —	2.24 11.2
Organic matter mg. KMnO ₄ /l:—		
Complete.....	7.0	7.7
After passing filter 366.....	6.6	—
After passing filter 368.....	6.4	—

This water is richer in phosphorus than the warm water, but, as we will see later, not nearly so rich in phosphorus as the upwelled water of the West coast collected at Saldanha. Further, the cold water is manifestly richer in phytoplankton, which can easily be corroborated by microscopical examination of the net-caught plankton. It is, on the other hand, very striking that the figures for readily oxidizable organic matter are comparable

with those for the warm water. Only a little of the organic matter was withheld by the filters 366 and 368. Evidently plankton does not rank first among the organic constituents of the water.

(iii) Some samples were collected in the middle section of the lagoon, between the Knysna railway bridge, and the new road bridge under construction, i.e. in the waters of greenish-grey colour:—

Station.	Belvedere: Station VIII. (Plate VI).	Grove's Jetty.	Belvedere Cove: Station VI. (Plate V).
Date.....	12/2/1953	26/2/1953	13/2/1953
Tide.....	L.W.	1 hr. after L.W.	1½ hr. after H.W.
Salinity.....	—	29.10/00	—
P. mg. atom/m ³	0.39	0.35	—
Pigment/l: (standard 1.0).....	430m μ 670m μ	430m μ 670m μ	—
Filter 365.....	0.76 2.8	0.66 2.2	—
Filter 366.....	— —	1.14 4.0	—
Filter 368.....	— —	1.90 12.6	—
Organic matter mg. KMnO ₄ /l.....	12.2	12.1	12.1
After passing filter 366.....	—	11.1	—
After passing filter 368.....	—	10.9	—

The total phosphorus content of this water does not differ noticeably from that in the warm ocean water, but the pigment content is higher, and the densest filter used withheld considerably more pigment-bearing plankton than did the coarser filters. This corresponds with observations on net-plankton, which revealed that pelagic diatoms are rather scarce in this water. Small flagellates and other small phytoplanktonic organisms escaping through the 70μ meshes of the plankton-net may be very abundant here.

The total quantity of organic matter exceeds that in the warm water and also that in the cold water considerably, but we cannot determine whether there are also qualitative differences. From analysis of the greenish-grey water after passage through the filters 366 and 368, it can be concluded that only a minor part of the organic matter is located in plankton or detritus particles

of fair dimensions. (It must be noted here that some small fibres of the filter paper may have obscured the difference somewhat. From observations with Oosterschelde water with non-fibre releasing filters, I feel sure that any filter paper fibres passing through can at most have caused a minor error).

I further analysed some samples which can be considered as intermediary between the categories (i), (ii) and (iii), i.e. samples of water from the oyster basin on Thesen's Island, which gets a constant supply of water from an inlet 4 metres under the surface at Thesen's wharf, and so directly from the main channel. This oyster pond contains ocean water at high tide and water from above the railway bridge at low tide. The tidal differences are therefore closely reflected by the quality of the water entering this pond:—

Station.....		Oyster Pond, Thesen's Island.						
Date.....	11/2/1953	23/2/1953						
Hour.....	—	8.45	11.40	12.40	13.10	14.10	15.30	17.45
Tide.....	L.W.	2 hr. flood.	—	—	H.W.	—	—	—
Temperature.....	—	24.9 C.	21.7 C.	19.9 C.	19.0 C.	18.5 C.	22.8 C.	25.6 C.
Salinity.....	—	33.6 ⁰ / ₀₀	—	—	—	—	—	—
P. mg. atom/m ³	0.27	0.36	0.41	—	—	—	—	—
Pigment/l: (standard 1.0)	430m μ 670m μ	430m μ 670m μ	430m μ 670m μ	—	—	—	—	—
Filter 365.....	0.54 2.4	0.58 2.4	0.54 2.2	—	—	—	—	—
Filter 368.....	—	0.96 4.6	—	—	—	—	—	—
Organic matter mg. KMnO ₄ /l.....	10.0	9.4	7.7	—	7.7	—	7.2	—

On February 23rd we saw how the cold water gradually replaced the low-tide mixed water with its rather high organic-matter figure, the latter water again prevailed later on in the day.

(iv) Only once did I sample from the Knysna River, i.e. on February 26th:—

Station.	Knysna River, above Charlesford Rapids, clear brown water.
Date.....	26/2/1953
Temperature.....	26.5°C.
Salinity.....	1.1 ⁰ / ₀₀
P. mg. atom/m ³	0.17
Organic matter mg. KMnO ₄ /l....	31.8

This almost fresh water is very poor in total phosphorus, but rich in readily oxidizable organic matter, presumably largely humic material. The daily run-off under normal conditions is very modest as compared with the daily influx of ocean water with the tides.

(v) The samples taken in other lagoons, lakes and inlets will be discussed in a later section.

(c) Discussion.

Though I admit that a greater series of analyses, including a study of possible seasonal differences, would give a more detailed picture of the fertility of the Knysna Lagoon, I feel sure that the data presented above, referring to some well-chosen sampling stations, are sufficient to conclude that the middle section of the Knysna Lagoon contains

more fertile water and shows a richer organic production (c.f. pigment data) and total organic matter than the regular warm inshore ocean water, which predominates in the downriver part of the lagoon for many hours a day, at least in the deeper channels. There is certainly not such a great difference in fertility between the blue ocean water and the rather turbid grey-green lagoon water, as would have been expected from their outward appearance alone. The warm blue ocean water is definitely not very poor in total phosphorus and organic matter.

The Knysna River, on the other hand, contains very little phosphorus, and no regular phytoplankton. Its organic matter may consist predominantly of humic acids and similar material.

The entire pattern resembles very much the conditions in some Australian East coast estuaries, analysed by Rochford (1951, 1952). In these Australian estuaries Rochford distinguishes three zones (see Plate XI):—

- (1) The upriver section, receiving the run-off of a river (water virtually devoid of waterborne phosphorus), and with a rather coarse sand-bottom poor in interstitial phosphorus compounds;
- (2) the downriver section, close to the mouth of the estuary, and bathed by neritic ocean water at high tide. The ocean water contains a fair amount of phosphorus, though most of it is in organic form; the sand-bottom of this section is poor in phosphorus compounds. Spatfall of oysters may be profuse in this section, but the oyster's growth and fattening is rather poor as a rule;
- (3) the intermediate zone, which may show rather low phosphorus values of the water, is characterized by a very high phosphorus content of its finely granular bottom deposits; growth and fattening of oysters is as a rule very good in the middle section of such estuaries. Large phytoplankton organisms are scarce in this section. Rochford gives neither pigment data nor other figures from which the importance of the nanoplankton can be assessed.

Rochford (1952) explains that "the productivity of the waters of the intertidal region, in which oyster fattening occurs, was governed by the rate and effectiveness of utilization of these mud-phosphates by a permanent surface trophic film of bacteria, microprotozoa, or sessile diatoms. *In situ* processes, probably bacterial, assisted by chemical processes, replaced these interstitial

phosphates by desorption and degradation of the adsorbed and insoluble phosphates on or within the mud particles. A continuous cycle of phosphate supply and organic production could thus be maintained at the mud surface".

Though I did not carry out any analysis of bottom deposits during my short sojourn at Knysna, there is no doubt that in the Knysna estuary, the middle section, with its extensive tidal mud flats and eelgrass fields, will be found to contain very much more total phosphorus and microbiota in its superficial bottom layers than the rather coarse sands of both the Knysna River and the downriver section of the estuary.

However true and interesting Rochford's explanation may be, it cannot possibly be the whole story, for it does not explain the origin of the fertility of the middle section of the east Australian estuaries. As far as I can see there are three possibilities: (1) the river discharges the nutrients primarily, which are then accumulated in the central section of the lagoon, and are only to a smaller degree washed out into the sea; (2) the fertility comes from the ocean itself and is apparently built up against a gradient; (3) the rich central area is a self-contained system, with its own perpetual phosphorus cycle, and suffers little, if any, losses into the sea, and so can maintain its fertility for a very long time, if not indefinitely.

It is clear that the third explanation increases the difficulty, for it will be necessary then to find a proper explanation of how the fertile material was brought and accumulated there in a geological past! Rochford does not discuss this problem. He evidently does not believe that the very poor river water is important as a source of estuarine fertility, and neither do I believe that the effluents of the Knysna River contribute materially to the productivity of the Knysna Lagoon! Neither in eastern Australia nor in Knysna are there extensive rich alluvial soils which are constantly lixiviated by drainage water pouring out into the estuary. Rochford seems to be convinced that the fertility of the east Australian estuaries is basically self-contained, and that no material contributions come from either the upriver or the downriver adjacencies. For, if oysters are grown there, and absorb whatever they need for their growth and fattening, and these oysters are later removed for marketing, Rochford deems it necessary to add some extra phosphates to replace the losses, if one wishes to maintain the fertility of the entire system. This parallels the regular agricultural practice, and certainly it is true that valuable phosphorus compounds and the like are taken away with the oysters, thus reducing the fertility of

the system. But it is not explained why the losses through lixiviation by the ocean water, which pours in with every flood, to retreat again with the ebb, are not much heavier than those suffered by the removal of the marketable oysters. Lixiviation will be the more serious in relation to more river water pouring into the estuary, thus increasing the surplus of ebb water. If the tides entering the estuary take away only a little fertility each time, why then has not its fertility been destroyed long ago?

My personal view on this very interesting and important problem is that *the source of all fertility in similar estuaries is to be found in the ocean itself!*

Though it may seem paradoxical at first glance that the fertility of the estuary's central section is built up against a gradient, there are several ways in which this really happens:—

- (1) Sedimentation of silt and small detritus particles does take place wherever the sea-water bearing some of it is temporarily immobilized. The enormous sedimentation in many harbours receiving no river water is a well-known example. The amount of silt and detritus settling in a carboy of apparently clear sea water is often surprising.
- (2) Wherever the flood currents are faster, but of shorter duration, than the ebb currents, the water may lose some of its sediment. In this respect we can mention the work of Postma (1951, 1954), who studied sediment accumulation in the Dutch Waddensea and demonstrated that the main source of silt must be sought in the North Sea.
- (3) That shellfish beds may contribute largely to the accumulation of silt and to increasing the total fertility of partly landlocked areas, follows from Verwey's (1952) most interesting studies on the populations of *Cardium* and *Mytilus* in the Dutch Waddensea. The Waddensea, if it were a completely closed basin, could never produce such large amounts of animals as actually do exist there. Through the constant filtering of the bivalves, silt, organisms, and detritus are taken from the North Sea water which comes in with every flood. Part of this is directly assimilated in the tissues of the shellfish itself, but a much larger portion is deposited in their pseudo-faeces and faecal pellets. These faecal pellets, which do not easily re-enter into suspension and therefore are not easily carried to the North Sea on the ebb tide, become available to a host of other benthic creatures. This again provides

a system of accumulation against a gradient. Verwey concludes that, though the high level of organic material reached within the Waddensea is certainly due to the favourable influence of the North Sea, the latter does little more than regularly add to the large amount of material already present, thus counteracting the losses, including those due to the local shellfish fishery.

This procedure may work in the Knysna Lagoon too, but undoubtedly on a more modest scale than in the Dutch Waddensea, for dense beds of bivalves or similar filter-feeders are not known in the Knysna area. In the central and upper sections of the Knysna Lagoon there are, however, locally large numbers of the small *Modiola capensis* (Krauss), each individual often hidden in a small potato-like agglomeration of a sticky clay, which it no doubt accumulated itself. Further we find here and there fair concentrations of *Solen capensis* (Fisher). Both *Modiola* and *Solen* certainly work on the same lines as the *Cardium* and *Mytilus* of the Dutch Waddensea.

- (4) There is, however, still another way in which an estuary may gradually accumulate valuable constituents from the incoming flood water, only part of which is lost again through being carried along to the sea in some form by the ebb.

The incoming ocean water is fairly rich in organic matter, most of it soluble or in colloidal form. Evidently marine bacteria are not in a position to utilize this organic matter on a large scale, most probably because truly pelagic bacteria are rather scarce. Marine bacteria are predominantly benthic and need a solid surface to develop great activity (ZoBell, 1943). Any particulate matter, including the larger planktonic organisms, may serve as a desirable type of solid substratum on which bacteria may develop, attacking the organic matter around them with their exo-enzymes, converting about 30 per cent of it into bacterial protoplasm, and mineralizing the remainder (Waksman and Carey, 1935, ZoBell and Grant, 1943). On the other hand, not only fishes and the like, but also all planktonic organisms, including their bacterial epiflora, excrete some organic matter. Evidently there is an equilibrium in the sea between production and destruction of "dissolved" organic matter, an equilibrium depending on the nature and number of organisms producing it and on the facilities bacteria find to break it down again. This temporarily "dead capital" of organic matter in the superficial layers of the ocean is

incredibly great. A few mg. of organic carbon per litre seems only little, but if calculated for even a rather modest bay or inlet it leads to impressive quantities.

Bacterial utilization of low concentrations of organic matter in sea water and the effect of solid surfaces upon bacterial activity have been studied in considerable detail by ZoBell and Anderson (1936), ZoBell and Grant (1943), and ZoBell (1943). They studied the changes in the quantity of organic matter in sea-water samples during storage in darkness. From the oxygen consumption observed it follows that the organic matter level is seriously lowered during storage because its production has been cut short in the dark, so that the equilibrium production $\rightleftharpoons$ destruction becomes displaced. It is further of great interest that the new level is reached within a shorter time according to whether there is more solid surface available. The smaller the glass bottles used the greater the bacterial activity, and the sooner the new equilibrium is attained. By adding glass tubing or glass beads to the bottles the process is speeded up considerably and much higher numbers of bacteria will be found during its height. Most of the bacteria appear to use the solid surface as a basis of operations. ZoBell and his co-workers stress the enormous advantages of solid surfaces for bacteria living in the low concentrations of organic matter which occur in natural sea water.

This phenomenon seems to me of paramount importance in studying biological processes in an estuary. The ocean water contains a fair amount of organic matter, a temporarily "dead capital", not directly to be utilized by the phytoplankton and therefore unattainable for the zooplankton. When this water enters the shallower part of the estuary with its complicated bottom configuration, its finely granular bottom deposits, and its extensive eelgras-fields and tidal mud-flats, this means a considerable increase in availability of solid surface, and what is more, a solid surface already teeming with marine bacteria! These immediately attack the organic matter with their powerful exo-enzymes and convert part of it into bacterial protoplasm—when more food is available than is needed to maintain their basic metabolism—which indirectly makes it readily available for a host of microbiota feeding on bacteria, and also for many a filter-feeder. According to Waksman and Carey (1935) and ZoBell and Grant (1943) up to 30 per cent of the organic matter may be converted into bacterial protoplasm. The remainder of the organic matter attacked by the bacterial enzymes is mineralized. The nannoplankton, among which small unarmoured flagellates predominate, immediately

assimilate the mineralized phosphorus and nitrogen compounds, and flourish. In their turn they constitute the main food for a variety of creatures, both planktonic and benthic. Part of the newly liberated mineral constituents is used by *Zostera* and similar submerged phanerogamous plants, which assimilate it and thus build up food for many creatures which live on their leaves or their remains.

Much of the valuable constituents of the originally "dissolved" organic matter in the ocean water is thus consolidated inside the estuary. A wealth of aquatic plants, both macroscopic and microscopic, both pelagic and benthic, can be built up inside such an estuary, irrespective of the quality and quantity of the inflowing river-water. A variety of benthic animals ensures that a great part of the nannoplankton is converted into less readily transportable organic material before the tidal currents get a chance to wash it out again into the sea. Some of the nannoplankton and their excreta are inevitably lost on the ebb, but so much is consolidated in a variety of forms, that the fertility of the estuary tends to increase continuously.

There is no doubt that a perpetual internal circulation in the manner described by Rochford operates inside the estuary, and that it will be possible to find the localities and levels where oysters will find their optimum feeding and fattening conditions. It is even possible that some extra addition of phosphates may promote the productivity of their food, but this is not necessarily so, for other factors than phosphates may be the limiting factors of productivity.

It seems improbable that the total biological balance within the estuary is so unstable that the removal of some marketable oysters will readily lead to a noticeable decline of its fertility. It is theoretically even possible that through the filtering activity of the oysters the estuary gains more organic material than it ultimately loses through the marketing of these oysters, for the consolidated matter contained in their faeces and pseudo-faeces is utilized by a variety of other creatures.

I do not pretend that the few analyses I could accomplish at Knysna give a complete picture of all the events described above. It would be very interesting to study all these processes quantitatively and in detail, but this would require years instead of weeks, and a well-equipped and staffed laboratory instead of the simple establishment I had at my disposal (see Plate XII, Fig. 1). Among other things it would be necessary to know more of the quality of the organic matter in sea-water. I surmise that many valuable constituents, including

phosphorus, nitrogen, and other biologically important elements, will be abundant in the ocean (c.f. Rochford's data on total phosphorus in the ocean water). In the estuary we may find quite a high figure for organic matter. Part of this represents nannoplanktonic organisms, and another part the excreta of the micro-flora, excreta in which the carbohydrate component may be found to prevail. In my view the fertility of the estuarine system is not so much governed by the total quantity of dissolved and suspended organic matter coming in with the flood as compared with that leaving with the ebb, as by the capture and consolidation from the incoming water of its more valuable components, i.e. those containing phosphorus, nitrogen and other biologically important elements, by the processes outlined above.

An interesting small-scale example is provided by a comparison of the data on two small rock-pools at Walker Point, presented above (see page 25). At first glance they differ very much: one was in open communication with the sea, and contained very clear water. The other was a rock-pool above high-tide level, filled by the spray, and contained rather turbid greenish-grey water, very rich in nannoplanktonic organisms (a monoculture of dinoflagellates about 15 to 20 μ in diameter; 125,000 per cc.); some green algae were attached to the rocky bottom, and some little fishes swam around in this pool. One would certainly have expected more total organic matter and more total phosphorus in the second pool. In reality we found rather less, and an insignificant difference in organic matter. I explain this unexpected finding in terms of bacterial breakdown of dissolved organic phosphorus compounds in the spray-filled pool, with its large amount of solid surface, and the building up of a flourishing flagellate population on the mineralized compounds. Total phosphorus and total organic matter in suspension hardly change, but are represented in quite a different form. Is it too bold to consider this case as a small-scale model of what is going on in the entire Knysna Lagoon?

8.—INDEGENOUS SPECIES OF OYSTERS AND THEIR QUALITIES FOR OYSTER CULTIVATION.

In selecting a site for establishing an oyster industry there is every reason to focus our attention on places where natural oyster beds occur or once occurred. For it follows as a matter of course, that all the conditions required for the entire development of the oyster are realised there. This is the basis of Ranson's (1951 a) opinion that "Les huîtres des 'bancs naturels' sont seules susceptibles d'assurer la pérennité de l'espèce". This verdict,

which could perhaps better be formulated "seulement les 'bancs naturels' d'huîtres sont susceptibles d'assurer la pérennité de l'espèce", should not imply, however, that an oyster industry can only be created on the site of a thriving or depleted natural bed. For at least some of the many conditions required by oysters, can be created artificially; and there are indeed thriving oyster industries which have been established in places where natural beds never existed.

We did not find any natural oyster beds in the Knysna Lagoon. Its deep channels, with a bottom of rather coarse shifting sand, its extensive eelgrass-fields and mud-flats, often honeycombed with the burrows of the mud-shrimp *Upogebia africana*, cannot be suitable for oysters. We did, however, find occasional oysters attached to rocks, jetties, and pillars of bridges. Apparently oyster larvae do occur in the lagoon, but evidently they find little chance to settle there. The large numbers of spat found on artificial collectors placed in the lagoon corroborate this view. Where oyster larvae are settling in significant numbers, there must be a reasonable population of adult oysters in the vicinity, unless it can be demonstrated that those larvae have been transported by currents over considerable distances. For the oyster industry at Knysna it is of considerable importance to know whether or not the indigenous oysters settling on the artificial collectors do belong to one and the same species, and to find out which are the qualities of the indigenous oyster(s), especially those pertinent to their suitability for oyster cultivation.

Samples of oysters collected from the rocks and from artificial collectors, brought to me by Mr. Bright and Mr. van Dort in earlier years, taught me that there are at least two species, and possibly three, of indigenous oysters in the Knysna district. Observations on young and adult oysters collected by me in the Knysna area have fully confirmed this view.

The various species of edible oysters all over the world belong to two categories, viz. the oviparous and the larviparous oysters, which differ so much in morphological, anatomical, and biological qualities, that it is inexcusable to lump them into one genus. The oviparous oysters spawn their eggs directly into the surrounding sea-water and can easily be recognised anatomically by the presence of the promyal chamber (see Plate XIII, Fig. 1), which separates part of the right mantle from the visceral mass, and through which a considerable portion of the water pumped by the gills is discharged. Further, the cupped valve of the

oviparous oyster often shows a well-developed umbonal cavity (see Plate XIII, Fig. 1), but lacks extensive layers of "chalky deposits" at the height of the gills and suprabranchial chamber (see Plate XIII, Fig. 1).

The larviparous or flat oysters, on the other hand, spawn their eggs on the gills, where they are incubated for several days, so that the larvae are not discharged into the surrounding sea-water before they have reached an advanced stage of development. There is no promyal chamber in flat oysters (see Plate XIII, Fig. 2), but the suprabranchial chamber is more spacious than in oviparous oysters because all the water pumped by the gills must pass through it. There is no umbonal cavity, but the cupped valve of older oysters—in very old individuals also the flat valve—shows ample "chalky deposits" opposite the gills and suprabranchial chamber (see Plate XIII, Fig. 2).

The larviparous or flat oysters are invariably assigned to the genus *Ostrea*, but in many papers also the oviparous oysters are treated as belonging to the genus *Ostrea*. I have discussed in detail (Korringa 1952) why oviparous oysters—differing in so many respects from the larviparous oysters—should be assigned to a different genus. Until recently there was, however, some difference of opinion as to the correct generic name, which should either be *Gryphaea* (widely used in Europe) or *Crassostrea* (used by many American authors in recent years). After completion of this manuscript No. 338 of the "Opinions and Declarations rendered by the International Commission on Zoological Nomenclature" appeared (dated March 17th, 1955) in which it is prescribed that henceforth the name *Gryphaea* should be used for fossil oysters only. To minimize confusion we should, therefore, use the generic name *Crassostrea* for the oviparous oysters.

Of the three species of oysters living in the Knysna area two are larviparous, the other oviparous.

(a) *Crassostrea* (*Gryphaea*) *margaritacea* (Lmk.).

The best known South African oyster is a typical oviparous oyster with a large promyal chamber, and often well-developed umbonal cavity, moreover with the type of larval shell (prodissoconch) characteristic for the genus. This is the oyster which is collected on a commercial scale in many places along the southern coastline—in particular between Mossel Bay and Jeffrey's Bay (Thompson, 1913)—and marketed in several cities of the Union. Its scientific name is *Crassostrea* (*Gryphaea*) *margaritacea* (Lmk.) and as a

popular name I would suggest "common South African oyster". In Stephenson's papers (1937, 1947) it is named *Ostrea iridescens* Gray and *Ostrea prismatica* Gray; Thompson (1913) refers to it as *Ostrea tuberculata*. The interior surface of the shell shows a slight pearly lustre (hence its scientific name "*margaritacea*"), and the path the adductor muscle followed during the growth of the oyster usually shows dark pigmentation. Very characteristic for this species is the fine radial ribbing of the prismatic layer of the flat valve. These densely placed radial ribs are already present in young specimens a few weeks old (c.f. Ranson 1951 b, Fig. 6), and this facilitates infallible recognition of the spat of *Crassostrea margaritacea*, even by the layman. Though the prismatic layer tends to scale off at a more advanced age, it is nearly always possible to find some undamaged site close to the shell's margin for its proper identification.

In outward appearance the common South African oyster resembles the rock oyster of Natal. Stephenson (1947) found the Natal rock oyster in great numbers from Umpangazi to Port Edward, less abundantly farther south, and only rarely as far south as East London. Evidently this is a typical warm water oyster requiring a minimum water temperature of 25° C. in summer. The radial ribbing of the prismatic layer of the flat valve in *Crassostrea margaritacea* (see Plate XIV, fig. 1) is, however, a foolproof feature to distinguish it from the Natal rock oyster, which latter is often named *Crassostrea* (*Gryphaea*) *cucullata* (Born) (Stephenson, 1947). I dare not decide whether or not this identification is correct, but if the Natal rock oyster is not identical with the Indian *Cr.* (*G.*) *cucullata* or the Australian *Cr.* (*G.*) *commercialis* (I. and R.) it is very closely related to them.

The shell of the common South African oyster, *Crassostrea margaritacea*, is very polymorphic in appearance; oblong types and nearly round ones, very deep shells and flat ones, may be found to co-exist in the same habitat. Evidently the conditions each individual oyster meets in the site it has once selected for fixation largely determine the ultimate shell shape. Like other oviparous oysters *Crassostrea margaritacea* has the facility for displacing its hinge considerably. A very deep but gradually filled-in umbonal cavity is then found in the cupped valve; the flat valve grows hardly at all, but gradually moves away from the place it once occupied, (see Plate XII, Fig. 2, upper row, Ranson 1951 b, Fig. 3). Though the oyster cannot detach its cupped valve from a site recognized as inadequate, the displacement of the hinge gives it a chance to survive and thrive. Oysters high in the intertidal zone may show a very stunted

growth, but those living under favourable conditions may develop enormous, though rather shapeless shells. Coloured oyster pickers recognize the various types and give them names such as *kraaibek*, *sonoester* and *horsepoot*, but it should be clearly understood that such names have no taxonomic meaning and merely denote adaptations to local environmental conditions.

We can adduce very interesting information on the biology of the common South African oyster, *Crassostrea margaritacea*. The habitat in which this oyster is collected on a commercial scale is a very unusual one for oysters, i.e. rocks at low water spring level on a sandy coast, and fully exposed to the surf of the ocean. Anyone familiar with this open coast, where rollers heavily loaded with sand grains pound the rocks to which the oysters are attached, (see frontispiece) would consider this a very inadequate habitat for oysters. Still, oysters not only abound here, but grow well and develop excellent quality of the edible parts. Shortly after the spawning season the oysters are already in such good condition that they can be collected for the market when tides and weather permit them to be detached from the rocks with a crow bar. This oyster evidently does not demand estuarine conditions for its optimal development. It thrives here in clear ocean water of a salinity of 34 to 35‰, and evidently finds enough food in it. Ranson (1943), who claims that oviparous oysters cannot thrive in waters of a salinity above 31‰, would be very surprised to see this! Commenting on some observations of van Dort's, Ranson (1951 b, pp. 15-16) mistakes readings of the specific gravity for salinity data. The real salinities, computed from the formula: $\text{salinity} = 1309 (\text{spec. gravity at } 17.5^{\circ}\text{C} - 1)$, after applying temperature corrections with Knudsen's tables, are all well above 30‰! There certainly is no reason to suppose with Ranson that offshore salinities must be higher than those observed by van Dort.

More unusual than life at high salinities is life in rough sand-laden waters, which would make it impossible for many other types of oysters to live and thrive. The Knysna oyster collectors informed us that they often found oysters attached to rocks buried under 30 to 40 cm. of coarse sand! In such cases there is no trace of blackening of the shells, and almost invariably the edible parts are in prime condition! Apparently the sand covering these oysters is coarse enough to permit circulation of water rich in oxygen, and evidently the oysters are even able to collect sufficient food from this water. Van Dort assured me repeatedly that he himself had often found fat and healthy oysters buried under a thick layer of coarse sand. However, when

the oysters become buried under a layer of very fine sand, they invariably die sooner or later and show the black-coloured shells indicating lack of oxygen.

Another interesting and important point is the taste and flavour of this oyster. Contrary to my expectations I found its flavour very good indeed, and even closely resembling that of the famous European flat oyster, *Ostrea edulis* L. The flavour of the South African oyster is so outstanding, indeed, that if its other qualities meet the requirements, there is no reason at all to introduce foreign oysters for relaying in South African waters.

From the experience of commercial oyster collectors along Africa's south coast, who can work at low spring tides and in calm weather only, it is clear that only the fringe of the natural population of oysters is touched. It certainly is not true what Ranson says (1949, 1951 b): "Sur la côte d'Afrique du Sud on ne trouve que des échantillons plus ou moins dispersés, fixés sur les rochers de la zone intercotidale". Undoubtedly there are countless millions of them attached to rocks out of reach and down to inaccessible depths. Occasional observations under exceptionally favourable conditions, and also the profuse settling on artificial collectors in the Knysna lagoon, clearly demonstrate this.

Unfortunately thus far we have very little experience on the growth rate of this oyster. It is of paramount importance to the oyster farmer to know how many years must elapse before the collected spat grow to a marketable oyster. Van Dort was unfortunate enough to lose, through carelessness of some unwelcome visitors, all the spat of this oyster collected early in 1949, and to find in later years that only few oysters of this kind attached to his collectors. Still, the good growth of the few which did survive on some collectors gave rise to the hope that this oyster may grow to marketable size within a reasonably short time. Nevertheless before concentrating exclusively on cultivation of these savoury indigenous oysters, one must collect more experimental evidence on its rate of development from spat to marketable oyster, and also on the losses normally suffered in the course of these years.

(b) *Ostrea algoensis* Sow.

Inspection of the first artificial collectors put down in the Knysna Lagoon and brought to Holland by the late Mr. Bright, revealed that they carried at least two different types of oysters, one with a fine radial ribbing of the flat valve's prismatic layer and with densely-placed blueish-purple pigmentation streaks, the other with a smooth texture of the flat valve's prismatic layer and with

a yellow colour, the latter sometimes broken by rather broad pigment bands, deep purple or almost black in colour (see Plate XIV, Fig. 2, and Plate I, Fig. 2).

I brought those collectors to Dr. G. Ranson of the Paris Museum of Natural History for proper identification of the oyster spat attached to them. Ranson confirmed that two different types of oysters occurred on the collectors, one an oviparous oyster, evidently *Crassostrea margaritacea*, characterized by a prodissoconch typical for the genus and by the fine radial ribbing characteristic of the species; the other without doubt a flat oyster of the genus *Ostrea*, as revealed by the features of the prodissoconch shell still recognizable at the umbo of the flat valve in well-preserved specimens. Ranson identified this flat oyster as *Ostrea algoensis* Sowerby, first described by the latter author from Algoa Bay, South Africa. Ranson presumes that *Ostrea algoensis* may be identical with the widespread *Ostrea stentina* Payraudeau, which is an oyster attaining a small size only. However this may be, the specimens of *Ostrea algoensis* from the Knysna district later brought to me by Van Dort and also those collected there by myself invariably were of small size only.

Van Dort detached thousands of spat of this oyster from his tiles and tried to rear them in trays covered with wire netting. Inspection of those oysters after one or two years of tray cultivation demonstrated that their growth had been rather poor, which was the more surprising because the spat had attained a fair size (15 to 25 mm.) in the first few months of sedentary life. In every respect the little oysters two years old appeared to be adult specimens, usually in good condition with creamy glycogen-bearing tissues around the viscera. Among specimens collected in December or early January I found several bearing larvae on the gills. This, together with the total absence of a promyal chamber, corroborated the identification by features of the shell that these specimens were larviparous oyster of the genus *Ostrea*.

It was rather surprising to find so many *Ostrea algoensis* on the tile collectors in the Knysna Lagoon, for practically all the oysters picked from the rocks along the coast appeared to belong to the oviparous oyster, *Crassostrea margaritacea*. We made a careful search in the Knysna Lagoon but found only a few adult specimens of this flat oyster. We found some attached to rocks near Featherbed Bay and about two dozen very old specimens attached to the piles of Grove's Jetty in the central part of the lagoon (see Plate III). The structure of the shells revealed that the latter specimens must be very old indeed, though they measured less than 2 inches across. Though this

flat oyster evidently occurs only in small numbers in the Knysna Lagoon, there must be millions somewhere in the neighbourhood to produce the larvae which settled so profusely on the tile collectors. Usually flat oysters settle in deeper water than the oviparous oysters, and moreover it is known that flat oysters of the genus *Ostrea* usually show a strong dislike for the rough sand-laden waters of the surf. I therefore surmise that the natural beds of this oyster are to be found somewhere offshore at a level not exposed at low spring tides. I do not know of any dredging operations carried out close inshore, which might have revealed the presence of natural beds of *Ostrea algoensis* in the Knysna area.

Both inspection of the few adult specimens of *Ostrea algoensis* and observation of their growth on tiles and in trays make it very probable that this oyster never attains a fair size. Its growth may be fair in the first year, but it tends to slow down soon. It is true that we may presume that selection of the best site to place the trays could lead to better results than thus far obtained, but I would be very surprised indeed to hear that *Ostrea algoensis* grows to a size of over 3 inches within a few years, as a good oyster should. The Langebaan experiment, described below, demonstrated that even under conditions suitable for several other species of oyster *Ostrea algoensis* showed very poor growth only (see Plate XV, Fig. 1). This corroborates my view.

Such small oysters are as a rule of little, if any, value for oyster cultivation. Still, there is a case of remunerative oyster growing with a small type, viz. the cultivation of the Olympia oyster, *Ostrea lurida* (Carpentier) in Puget Sound, Washington, U.S.A. This oyster does not attain a size much over that of *Ostrea algoensis*, and it takes several years to grow them to a diameter of $1\frac{1}{2}$ to $1\frac{3}{4}$ inch. Its flavour is, however, so much superior to that of the fast-growing large-sized Japanese oyster (*Crassostrea gigas* Thunberg), that it can maintain its place on the market beside this giant, for the public pays a good price for it. Such a development is, however, most improbable in South Africa, for the flavour of the common South African oyster, *Crassostrea margaritacea*, leaves nothing to be desired. Further, in contrast to the Puget Sound area, where the small Olympia oyster is the native one, and the Japanese oyster was introduced much later, the South African oyster-eating public is already used to a fair-sized marketable oyster.

As far as my experience goes, we should therefore consider *Ostrea algoensis* as a "weed-oyster". Efforts should be made to avoid its fixation on the tile collectors and to concentrate on catching the

common South African oyster. Cultivation of specimens of *Ostrea algoensis* already attached should be reduced to a few small-scale experiments, to avoid serious loss of time, money, and material. It will be discussed in a following section how the oyster-farmer can avoid the settling of the weed-oyster *Ostrea algoensis* on the tile collectors placed in the Knysna Lagoon.

(c) *Ostrea atherstonei* **Bullen Newton.**

Credit should be given to Mr. van Dort for finding a third species of oyster, living usually well below the low water line and moreover a species hitherto not known to live in South African waters or anywhere else in the world. Van Dort recognized this oyster immediately as a flat oyster and described its flavour as outstanding. The shell Mr. Bright brought me of this oyster revealed all the features characteristic of a flat oyster: a well-rounded shape, the absence of an umbonal cavity, the presence of extensive layers of "chalky" deposits opposite the suprabranchial chamber, and the non-pigmented attachment site of the adductor muscle. The shell was, however, very much larger than those I had thus far seen of *Ostrea algoensis*, and moreover they made very much the impression of having been formed within a few years only. Evidently this oyster is a very fast grower. Further, both the texture and the colour of the shell differed noticeably from those of *Ostrea algoensis*: the prismatic layer of the flat valve has a rather rough, scaly and imbricate appearance instead of the smooth texture of *Ostrea algoensis*; the colour of its flat valve is predominantly wine red and shows no trace of yellow or black banding, and the cupped valve shows a pink tinge in many places, even in its deeper layers and "chalky" deposits.

I sent the shells of this large red flat oyster to Dr. Ranson for identification. Ranson informed me that the only flat oyster to be found on the coast of South Africa is the small *Ostrea algoensis* (syn. *O. stentina*): "La seule huître plate de cette région est l'*Ostrea stentina* (*O. algoensis*) qui reste toujours petite, mais qui est un vrai *Ostrea*" (Ranson, in litt. 6/1/1951). Oysters as large as I sent him could not possibly belong to that species and therefore should be reckoned to belong to the species *Crassostrea margaritacea*, no other oyster being known from Africa's South coast. In his 1951 b paper Ranson depicts the shell of van Dort's large red oyster in Figures 4 and 5 as "*Gryphaea margaritacea*, broadly attached and lacking an umbonal cavity".

It is the feeling of many practical oyster growers that similar disputes over nomenclatural problems are of academic value only. The great practical importance of an irrefutable solution of this very

taxonomic problem is obvious, however. We must be sure indeed in ascribing the red-coloured oyster to either the genus *Crassostrea* or the genus *Ostrea*. In the former case one could consider it with Ranson as a somewhat aberrant form of the common South African oyster, *Crassostrea margaritacea*, and henceforth pay little attention to it. In the latter case the question would arise whether the red oyster is an *Ostrea algoensis* or some other, thus far unknown, species of *Ostrea*. Of a small and apparently juvenile specimen which Van Dort sent me, Ranson stated "sans aucune doute il s'agit d'un *Ostrea algoensis*" (in litt. 22/12/1951). Would it be possible that *Ostrea algoensis* does grow rapidly and to a fair size under certain favourable conditions? If so the Knysna oyster industry could profit enormously from this knowledge, since it harvests annually so many young *Ostrea algoensis* on its tile collectors. Reared in the proper site, this spat would be valuable and I would—with pleasure—revise my opinion that *Ostrea algoensis* is a weed-oyster to be avoided in cultivation!

This is why I paid much attention to this taxonomic problem, and asked Van Dort to collect more specimens, some of which should be preserved in alcohol. The arrival of two intact large specimens (75 to 85 mm. in diameter) of the red oyster gave the irrefutable solution of the generic question: there was no trace of a promyal chamber! Evidently the red oyster belongs to the genus *Ostrea*, as Van Dort had presumed from the very moment (December 4th, 1949) he found his first specimen. The shell characteristics, namely, round shape, absence of umbonal cavity and presence of "chalky" deposits opposite the suprabranchial chamber corroborate this conclusion. When I showed these two complete specimens to Dr. Ranson in March, 1952, he was convinced that this oyster is a larviparous oyster of the genus *Ostrea*, and that the view expressed in his 1951 paper needed correction.

The second question, viz. determination of the species to which this oyster belongs, is of greater importance still, but was not so easily settled. As greater numbers of specimens came in the confusion was cleared up. All the large specimens showed the following shell characteristics: nearly round shell, resembling in shape that of a well-grown *Ostrea edulis*; growth rings and "chalky" deposits indicating rapid growth; prismatic layer of the flat valve of a scaly nature, rather rough in appearance, with a distinct wine red pigmentation; calcite ostracum of both valves in many places with a pink tinge. On the Knysna tile collectors were found several young oysters resembling these

large shells in colour and texture (see Plate XVI, Fig. 1). The large majority of the flat oysters from the collectors, however, showed a different appearance: in their second and third year slow growth and a tendency to become somewhat pear-shaped; smooth texture and yellowish-grey colour, sometimes with broad dark pigmentation bands on the exterior surface of the flat valve; inner surface of both shells often with a faint olive-green-grey tinge, never a pink hue. Comparison of the soft parts in oysters of similar size revealed (see Plate XVI, Fig. 2) that in the red oyster the adductor muscle is placed almost centrally and nearly parallel to the hinge, whilst in the true *Ostrea algoensis* this is sited more aborally and at an angle of about 45°. A midline let down from the hinge cuts off about $\frac{1}{3}$ of the adductor muscle in the red oyster, but passes orally of it in *Ostrea algoensis*. In *Ostrea algoensis* the gills are distinctly broader than in the red oyster. All these differences in size, shape, colour and texture, and in the morphological features of the soft parts, demonstrate that there are two species of flat oyster in the Knysna area. The decisive evidence was adduced in Ranson's laboratory, where he measured the prodissoconch of spat of the two types of flat oyster taken from tile collectors and found such a marked difference that the existence of two species of flat oyster could be established.

The next point was the proper identification of the large red *Ostrea* oyster. It was Ranson who identified it as *Ostrea atherstonei* (Bullen Newton), named after Dr. Atherstone, who was once very interested in the oysters of South Africa. Bullen Newton (1913) described this same oyster from quarternary layers on Africa's South coast (Alexandria beds of Bushman's River, Grass Ridge, and Zwartkops), and it was not known that this oyster had survived up till our times. This problem being settled, we wondered whether this oyster lives perhaps also in other places along Africa's South Coast. Van Dort collected several large specimens close to the Heads in the Knysna Lagoon, and it is said that fair numbers of it could be found attached to the rocks at the Heads, western shore, only within reach at exceptionally low tides in calm weather. Almost all of the oysters we picked up in the Keurbooms Lagoon on February 16th, 1953, appeared to belong to this species. In the show-collection of the South African Museum, Cape Town, I saw several fine specimens of *Ostrea atherstonei*, classified under a variety of names. These came from Port Alfred, Port Elizabeth and Muizenberg and other localities. There are also some specimens in the collection of the Department of Zoology of the University of

Cape Town, dredged on a rocky plateau in False Bay. These specimens were attached to small-sized collectors, which facilitated their collection by dredging. Obviously this oyster lives in many places along the South coast, but always below the low water spring tide level, and therefore out of reach. I have been told that there may be quite a few oysters in False Bay.

Considering the shape, size and colour of the shell we wondered whether this oyster might be identical with the species of which such enormous layers of shells occur in Saldanha Bay. Inspection of many shells, some collected commercially by the Pearl Oyster Co. in the central part of the Bay (see Plate XV, Fig. 2), and others from undisturbed layers in the saltings of the upper end of the Bay near the Geelbek farm, clearly demonstrated that these oysters too should be named *Ostrea atherstonei* (Bullen Newton). These well-preserved shells have the same size and shape, lack an umbonal cavity, but possess "chalky" deposits opposite the suprabranchial chamber, and moreover show the same pink tinge in many parts of the shell and the wine red colour of the prismatic layer of the flat valve. The absence of radial ribbing on the flat valve's prismatic layer gives further proof that this oyster certainly is not identical with the common South African oyster, *Crassostrea margaritacea*, as Ranson concluded in his 1951b paper: "appartiennent sans aucune doute possible à l'espèce *Gryphaea margaritacea* (Lmk.)". Ranson told me that it was the large size of these oysters and his ignorance of the existence of a large flat oyster in South African waters that had led him astray. It was striking to note that the oysters in the Saldanha Bay layers are nearly all separate from each other, even in the undisturbed layers in the Geelbek saltings. This is rather unusual, since, it is so often observed on natural beds that one generation of oysters settles upon the shells of the older generation, the new-growth shoots of the shells being the only type of collector which is readily available there. The shells I inspected all made the impression that the larvae of these oysters once settled by preference on very small natural collectors. It is not known which factor led to the destruction of the once so flourishing beds of *Ostrea atherstonei* in Saldanha Bay. Since all the shells are now covered by rather thick layers of sand or clay, one could presume that smothering by silt or sand in a period of increased run-off of rivers brought disaster, but it also seems possible that the red-tide phenomenon, so common on South Africa's West coast was responsible for the destruction of the oysters. The flatness of the top layer of shells uncovered in our

presence in the Geelbek saltings is very striking, and indicates that these beds may have been wiped out rather suddenly, unless it could be shown that the shells, which often still occurred in pairs, had been transported by water after the death of the oysters.

It is very interesting to note that *Ostrea atherstonei* did not disappear completely from Africa's West coast. Professor Day of the University of Cape Town sent a very small specimen from the shore at Hoedjes Bay to Dr. Ranson, and Mr. H. H. Thesen, Director of the Knysna Oyster Company, detected large numbers of this oyster attached to big concrete blocks used to keep submarine netting in its place at the entrance of Saldanha Bay in the war years. We inspected these oysters—now dead since the blocks were kept ashore at Saldanha—and found some large specimens several years old and a great number of yearlings, indicating that settling is rather erratic near Saldanha, which may be due to a limited parent stock somewhere in the vicinity, or/and to rather low water temperatures at the time of reproduction. So the red oyster, *Ostrea atherstonei*, does still occur on Africa's West coast.

Long ago diamond thieves tried to obtain permission to collect oysters near the mouth of the Orange River. Maybe oysters really occur in that forbidden area. If so, in all probability it will be *Ostrea atherstonei*.

Considering the excellent flavour, fine shape and rapid growth of the red oyster, there is every reason to think of *Ostrea atherstonei* as a perfect oyster for cultivation. Unfortunately such small numbers settle on the collectors in the Knysna Lagoon, that it seems questionable whether there is a possibility to collect its spat on a commercial scale. Small-scale experiments, to be carried out for example in Keurbooms Lagoon and/or at the Muizenberg shore, could demonstrate whether or not fair numbers of spat would settle there on collectors placed in December or early January. If suitable shells are available, I would also recommend an experimental planting of shell cultch on the flat-rock plateau in False Bay, where the fine specimens of *Ostrea atherstonei* mentioned above, were dredged. If no place can be located where *Ostrea atherstonei* settles on artificial collectors in significant numbers, it will be extremely difficult to use this excellent oyster for cultivation for only the still very hazardous system of tank breeding would provide a possibility of producing large numbers of offspring. The layman's conception that it will be sufficient to concentrate under natural conditions, a few hundreds or thousands of adult oysters and to place collectors

around them, will not work, since the larvae produced will be scattered over too wide an area during their pelagic life to settle in sufficient numbers on the collectors offered.

The foregoing discussions clearly demonstrate that correct and irrefutable identification is certainly not a matter of purely academic value. Identification does not only offer the key to further literature, but in this particular case leads to sound advice on the commercial policy to be followed by the Knysna oyster industry, regarding the type of oyster to be avoided, and the oyster to be selected for further work. The note placed with the poorly-identified oysters in the show collection of the South African Museum, Cape Town, "Dit word egter gesê dat oesters geëet moet word en nie geklassifiseer moet word nie" is manifestly an inexcusable excuse!

9.—OYSTER LARVAE IN THE KNYSNA AREA.

When travelling southwards I was especially looking forward to a search for oyster larvae in the Knysna area; not in the first place because nobody else had as yet observed, illustrated or described the pelagic larvae of the South African oysters, but more particularly to verify whether there could be any truth in the rather fantastic hypotheses launched by Ranson (1949, 1951 b): On the assumption that larvae of oviparous oysters required higher water temperatures and considerably lower salinities than were to be found in the coastal waters of Southern Africa, and that only some scattered adult oysters were attached to the rocks along the coast, Ranson surmised that the larvae of *Crassostrea margaritacea* settling on the collectors placed in the Knysna Lagoon must come from the far-away natural beds on the coasts of the island of Madagascar: "Je pense que les larves ayant donné naissance à tous ces échantillons côtiers jusqu'au Cap, aussi bien qu'à ceux fixés sur les collecteurs artificiels dans la lagune de Knysna, sont originaires des bancs naturels de la Baie de St. Augustin et de Fort Dauphin. Elles ont été transportées sur les côtes de l'Afrique du Sud par le courant esd Aiguilles". (Ranson, 1951 b). I explained earlier (Korringa, 1952) why I would certainly have been amazed if this hypothesis was found to be true. In the first place there were definitely much richer beds of *Crassostrea margaritacea* along the South African coast than Ranson assumed ("on ne trouve que des échantillons dispersés"); locally the oysters were even picked on a commercial scale, so that there was no reason to assume that the parent stock would be too limited for the normal rejuvenation of the population. In the second place there was not the slightest experimental

evidence that *Crassostrea margaritacea* or other species of this genus had such a narrow ecological range as Ranson claimed: "Or les constantes physiologiques du developpement de l'oeuf et de la larve fixent impitoyablement les régions favorables à la reproduction des huitres". (Ranson, 1951 b). But even if it were true that the eggs and larvae of *Crassostrea margaritacea* cannot develop normally in waters of high salinity, Ranson's hypothesis would imply that the larvae produced on the natural beds of southern Madagascar were swept along by the currents almost without delay, and remained within the Agulhas Current in rather brackish pockets of coastal water, for only such water is said to allow their normal development. Leaving out of consideration whether such brackish pockets of water really existed and persisted in the Agulhas Current, the distance to be covered was an insurmountable barrier, even for larvae making a bee-line for the Knysna Lagoon. The shortest distance between southern Madagascar and Knysna is about 2,500 Km., and the velocity of the Agulhas Current is approximately 50 Km. per day (according to Dietrich, 1935). It would therefore take the larvae about 50 days to reach Van Dort's collectors. This is considerably more than the regular three weeks the larval development of oviparous oysters requires.

Another point is that any larvae coming from the east in the Agulhas Current have little, if any, chance to enter directly into the Knysna Lagoon because, as Isaac (1937) points out, a counter-current going from West to East runs close inshore. Therefore most, if not all, of the pelagic larvae of benthic invertebrates coming into the Knysna Lagoon with the flood originate from parent stocks west of Knysna.

It is obvious that further examination of plankton samples could demonstrate whether or not there is an element of truth in Ranson's assumptions.

Fortunately it was known at which time of the year the indigenous South African oysters reproduced. As long as 60 years ago, Weatherley recorded (Anon., 1894): "Even though all the rocks and rocky points of the Zwartkops River abound in native African oysters, it was not at the commencement of the experiment known at what time of the year the native oyster spawned. This, however, has now been decided, for during the whole of January the oysters were spawning, and it was quite easy to collect the spawn for microscopic examination". This tallies very well with van Dort's experience that collectors placed late in December or in the course of the month of January receive a much greater number of young oysters than tiles placed either earlier or later. Van Dort also witnessed repeatedly the simultaneous spawn-

ing of adult oysters taken from the rocks and temporarily stored in his oyster basin; this invariably in the months of January or early February. When so many oysters are kept closely together at the height of the season of reproduction and in water of a rather high temperature, the sex products ejaculated by one single oyster can easily lead to wholesale spawning through the phenomenon of mutual spawning stimulation, well-known in other oviparous oysters. These observations demonstrate already that *Crassostrea margaritacea*'s gonad development takes place satisfactorily at the salinities 34 to 35‰ and the temperatures 22° to 24° C. prevailing in summer along the coast in the Knysna area, but also that an apparently normal spawning does take place at the salinities prevailing in the oyster basin at Thesen's Island, viz. 31 to 35‰.

A few days after my arrival at Knysna I began collecting plankton samples, first by towing a plankton net along the surface, later by pumping up known volumes of water (100 litres) from a known depth. I did not preserve the samples, for I preferred to observe the organisms caught alive. If time did not allow immediate examination, I placed the samples in a refrigerator, by means of which procedure lamellibranch larvae and the like may be kept alive for several days.

In the first few samples, taken on January 19th and 20th, I could not find any oyster larvae, but in a sample collected at Thesen's wharf at low tide on January 21st, I found one unmistakable oyster larva, in a rather advanced stage of development and with a pink tinge, measuring about 230 μ . The next day there were several more and on January 23rd I counted well over a hundred oyster larvae, measuring from 115 to 300 μ , in 100 litres of water collected at high tide from a depth of 2 m. at the black buoy near the Knysna Heads. A striking similarity in colouration and a gradual transition in shape with increasing size left no doubt that they all belonged to the same species of oyster. From the first moment I saw them I concluded that these were the larvae of *Crassostrea margaritacea*. There is a striking resemblance to the larvae of *Crassostrea gigas* as illustrated in figure 9 of Cahn's 1950 paper (see Plate XVII). The smallest larvae observed, measuring from 115 to 130 μ , are of identical shape to the one denoted with the letter "O" in Cahn's figure. Apparently the shells of the larvae of these oysters develop a pronounced umbo at a much earlier stage than in flat oysters, presumably at about the third day of their development. As the development proceeds the umbo of the cupped valve preponderates more and more (see Plate XVIII, Fig. 1). Moreover,

TABLE II.

PLANKTON SAMPLES—KNYSNA LAGOON.

Date.	Station.	Time.	Tide.	Net used.	Sample.	Temperature.	Salinity.	Number of Larvae of <i>Crassostrea margaritacea</i> .								Remarks.
								110-130μ	130-160μ	160-190μ	190-220μ	220-250μ	250-280μ	280-310μ	310-330μ	
1953						°C.	‰									
19/1	Featherbed Bay.....	11.00	L.W.	110μ mesh	Tow 10 ft. surface	—	—	—	—	—	—	—	—	—	—	Many gastropod and lamellibranch larvae.
20/1	Featherbed Bay.....	11.00	L.W.	110μ mesh	Tow 10 ft. surface	—	—	—	—	—	—	—	—	—	—	Many Copepods and gastropod and lamellibranch larvae.
21/1	Off Thesen's Wharf.....	11.00	L.W.	110μ mesh	Pump 100 l; 2 m.	—	—	—	—	—	—	1	—	—	—	
22/1	Railway Bridge.....	9.45	H.W.	110μ mesh	Pump 100 l; 2 m.	—	—	—	—	—	1	—	—	—	—	Many lamellibranch larvae, few Copepods.
22/1	Off Yacht Club, Knysna.....	10.00	H.W.	110μ mesh	Tow 5 ft. surface	—	—	—	1	—	1	1	3	—	—	Many Copepods and lamellibranch larvae.
23/1	Heads, Black Buoy.....	10.30	H.W.	110μ mesh	Pump 100 l; 2 m.	—	—	9	25	11	40	31	43	4	—	Very many lamellibranch larvae.
23/1	Off Thesen's Wharf.....	11.15	1 hr. ebb	110μ mesh	Pump 100 l; 2 m.	22.0	—	6	18	9	37	33	38	11	—	Many lamellibranch larvae.
26/1	Off Thesen's Wharf.....	8.30	L.W.	110μ mesh	Pump 100 l; 2 m.	25.0	33.8	—	3	4	10	15	25	2	—	Oyster larvae dull or dead.
26/1	Railway Bridge.....	9.30	L.W.	110μ mesh	Pump 100 l; 2 m.	25.0	32.9	—	—	1	2	4	1	1	—	Oyster larvae dull or dead.
26/1	Heads, Black Buoy.....	14.00	H.W.	110μ mesh	Pump 100 l; 2 m.	24.0	35.0	—	4	8	8	10	20	21	—	Oyster larvae healthy.
26/1	Heads, Black Buoy.....	14.15	H.W.	70μ mesh	Pump 100 l; 2 m.	24.0	35.0	3	5	2	3	—	5	12	1	
28/1	Off Thesen's Wharf.....	14.15	End flood	110μ mesh	Pump 100 l; 2 m.	24.0	36.0	1	4	2	1	2	5	20	—	
29/1	Off Thesen's Wharf.....	9.05	End ebb	110μ mesh	Pump 100 l; 2 m.	25.0	35.0	—	1	2	—	1	—	7	—	Part of oyster larvae unhealthy.
29/1	Featherbed Bay.....	12.20	2 hr. flood	110μ mesh	Pump 100 l; 2 m.	24.0	36.0	—	1	—	—	2	—	4	—	Oyster larvae healthy.
30/1	Off Yacht Club, Knysna.....	15.20	4 hr. flood	110μ mesh	Pump 100 l; 2 m.	24.0	36.0	—	1	6	4	—	5	20	—	Secchi disc 3 m. greenish water.
30/1	50 m. further South.....	15.40	—	110μ mesh	Pump 100 l; 2 m.	23.0	37.0	—	1	1	3	—	2	4	—	Secchi disc 5 m. clear blue water.
2/2	Off Thesen's Wharf.....	8.30	3 hr. ebb	110μ mesh	Pump 100 l; 2 m.	23.0	36.0	—	1	5	1	—	4	9	—	Secchi disc 3 m.
3/2	Off Leisure Island.....	9.00	2½ hr. ebb	110μ mesh	Pump 100 l; 2 m.	23.0	37.0	—	1	1	5	2	2	9	1	Secchi disc 4 m.
3/2	S.W. Corner, Downriver Section.....	9.20	3 hr. ebb	110μ mesh	Pump 100 l; 2 m.	23.0	37.0	—	—	—	—	—	—	—	—	Secchi disc 2½ m.
4/2	2 Km. South of Wharf.....	9.20	2 hr. ebb	110μ mesh	Pump 100 l; 2 m.	22.0	37.0	—	—	—	1	3	1	2	2	Secchi disc 4 m.
4/2	2 Km. South of Wharf.....	16.20	4 hr. flood	110μ mesh	Pump 100 l; 2 m.	23.0	37.0	—	—	1	—	2	1	—	—	Secchi disc 3½ m.
6/2	Off Thesen's Wharf.....	8.45	H.W.	110μ mesh	Pump 100 l; 2 m.	22.0	37.0	—	—	1	2	—	—	2	2	Many gastropod, and lamellibranch larvae.
9/2	Heads, Black Buoy.....	11.50	H.W.	110μ mesh	Pump 100 l; 2 m.	22.0	—	—	—	—	—	2	—	—	—	Several <i>Anomia</i> larvae.
9/2	Off Thesen's Wharf.....	12.55	1 hr. ebb	110μ mesh	Pump 100 l; 2 m.	22.0	—	—	—	—	—	—	1	—	—	
9/2	Entrance, Oyster Basin.....	13.10	1 hr. ebb	110μ mesh	Bucket 100 l; 1 m.	22.0	—	—	—	—	—	—	—	—	—	
10/2	Off Thesen's Wharf.....	16.45	Half ebb	110μ mesh	Tow 5 ft. surface	—	—	—	—	—	—	1	1	—	—	12 <i>Ostrea</i> larvae, many gastropod and lamellibranch larvae
10/2	Off Thesen's Wharf.....	16.45	Half ebb	70μ mesh	Tow 5 ft. surface	—	—	—	—	—	—	—	—	—	—	Also smaller lamellibranch larvae.
12/2	Belvedere Stake.....	14.30	H.W.	70μ mesh	Tow 5 ft. surface	—	—	—	—	—	—	—	—	—	—	Many thousands larvae of <i>Modiola capensis</i> .
12/2	Off Thesen's Wharf.....	16.30	2 hr. ebb	110μ mesh	Pump 100 l; 2 m.	—	—	—	—	—	—	—	5	4	—	1 <i>Ostrea</i> larva.
13/2	Belvedere Cove.....	12.00	Half flood	110μ mesh	Pump 100 l; 2 m.	25.0	—	—	—	—	—	—	—	2	—	<i>Crassostrea</i> larvae dead, many <i>Modiola</i> larvae.
13/2	Off Thesen's Wharf.....	16.00	H.W.	110μ mesh	Pump 100 l; 2 m.	—	—	—	—	—	—	5	4	16	—	
16/2	Off Thesen's Wharf.....	17.00	End flood	110μ mesh	Pump 100 l; 2 m.	—	—	—	—	—	—	1	—	8	1	
18/2	Entrance, Heads.....	16.55	Half flood	110μ mesh	Tow 3 ft. surface	—	—	3	—	—	4	12	61	115	1	Very rich zooplankton.
18/2	2 miles offshore, Heads.....	16.30	Half flood	110μ mesh	Tow 5 ft. surface	24.0	—	—	—	—	—	—	17	41	—	Several other lamellibranch larvae.
19/2	Off Thesen's Wharf.....	8.30	H.W.	110μ mesh	Pump 100 l; 2 m.	—	—	—	—	—	—	—	—	8	—	
20/2	Off Thesen's Wharf.....	10.30	H.W.	110μ mesh	Pump 100 l; 2 m.	—	—	—	—	—	—	—	1	10	1	
20/2	Entrance, Oyster Basin.....	11.00	H.W.	110μ mesh	Bucket 100 l; 1 m.	—	—	—	—	—	—	—	1	2	—	
23/2	Heads, Black Buoy.....	11.30	End flood	110μ mesh	Pump 100 l; 2 m.	15.0	—	—	—	—	—	—	1	1	—	Cold water, different plankton, many <i>Noctiluca</i> .
23/2	Heads, Black Buoy.....	11.45	End flood	110μ mesh	Tow 5 ft. surface	15.0	—	—	—	—	—	—	—	—	—	<i>Noctiluca</i> , <i>Ceratium</i> , diatoms.
24/2	Featherbed Bay.....	14.30	H.W.	110μ mesh	Pump 100 l; 2 m.	17.0	—	—	—	—	—	—	—	—	—	No larvae benthic organisms.
24/2	Featherbed Bay.....	14.30	H.W.	70μ mesh	Tow 5 ft. surface	17.0	—	—	—	—	—	—	—	—	—	
25/2	Heads, Black Buoy.....	14.30	H.W.	110μ mesh	Pump 100 l; 2 m.	15.0	—	—	—	—	—	—	—	—	—	
26/2	Heads, Black Buoy.....	14.00	End flood	110μ mesh	Pump 100 l; 2 m.	17.0	—	—	—	—	—	—	—	—	—	<i>Ceratium</i> and diatoms abound.
27/2	Heads, Black Buoy.....	14.00	End flood	110μ mesh	Pump 100 l; 2 m.	18.0	—	—	—	—	—	—	1	—	—	Still typical cold water plankton.
3/3	Featherbed Bay.....	11.30	L.W.	110μ mesh	Pump 100 l; 2 m.	21.0	—	—	—	—	—	—	—	—	—	
3/3	Featherbed Bay.....	17.00	H.W.	110μ mesh	Pump 100 l; 2 m.	13.0	—	—	—	—	—	—	—	—	—	
3/3	Featherbed Bay.....	17.00	H.W.	70μ mesh	Tow 5 ft. surface	13.0	—	—	—	—	—	—	—	—	—	
5/3	Featherbed Bay.....	17.00	End flood	110μ mesh	Pump 100 l; 2 m.	17.0	—	—	—	—	—	—	—	—	—	Many diatoms and <i>Ceratium</i> .

the larvae ready to settle, and provided with a distinct black pigment spot called "eye-spot" (see Plate XVIII, Fig. 2), are asymmetrical, in contrast to "mature" larvae of oysters of the genus *Ostrea*, which have an almost symmetrical shell. It is easy to distinguish the larvae of *Crassostrea margaritacea* from all other lamellibranch larvae encountered in the Knysna plankton—this not only because of the very characteristic shape of the oyster larvae, but also because of their typical colour pattern. Larvae in all developmental stages show a pink or faintly purple hue at the umbo. Further, there is in the full-grown larvae a large and very dark pigment field in the oral region (see Plate XVIII, Fig. 2). The digestive gland showed an orange colour in the larger larvae, but this may be liable to exception in other places or seasons when another type of food organism predominates. The velum showed a brown pigmentation and the prodissococonch itself is, with the exception of its umbo, of a yellowish-grey colour.

From January 23rd to February 3rd I counted fair numbers of oyster larvae in the plankton samples (see Table II).

Larvae ready to settle, provided with an "eye-spot" and measuring from 290 to 325 μ , predominated in the samples collected from January 26th to February 6th, indicating that this might be a very suitable time for placing collectors. Next followed a period in which only occasional oyster larvae were observed, but on February 18th, 19th and 20th I again found great numbers of larvae of *Crassostrea margaritacea*, among which was a striking proportion of "eyed" larvae, ready to settle.

Tile collectors were placed at intervals of about a fortnight, all at the station in Featherbed Bay (see Plate XIX, Fig. 1). From an inspection early in March, 1953, we could conclude that by far the largest number of spat of *Crassostrea margaritacea* had settled on tiles placed late in January, a result which tallies very well with our plankton investigations.

Still, the results of our investigations on oyster larvae in the Knysna Lagoon differ in many respects from the knowledge gained in the Dutch oyster district, the Oosterschelde. It is obvious that in both cases the larvae observed are produced by rather important concentrations of parent stock. In the Dutch oyster district the parent stock is located at the upper end of the inlet (Oosterschelde), and it is here that we find the largest numbers of larvae in summer. These larvae travel seawards on the ebb current, but nearly all of them return with the next flood. Plankton samples taken at the mouth of the Oosterschelde are almost devoid of oyster larvae. In the central section we find few

larvae at high tide, but large numbers at low tide when the water from the upper part of the estuary comes down to this district (Korringa, 1941). The day to day fluctuations in the number of larvae per unit of water are as a rule not very great in the upper district. Emission of large numbers of young larvae by the parent oysters may lead to a rather sudden numerical increase, but these larvae may become dispersed over a greater volume of water in the next few days, which results in an apparent decrease. The number of larvae in later developmental stages (umbo larvae, measuring over 220 μ in *Ostrea edulis*) shows considerably smaller fluctuations than those of the very young straight-hinge larvae. "Mature" larvae, provided with an "eye-spot" never make a sudden appearance in the Oosterschelde, but follow after a gradual numerical increase of the umbo-larvae. Unavoidable losses through depredation and dispersion ensure that there are always noticeably fewer "eyed" larvae than "umbo" larvae, and also fewer "umbo" larvae than there were straight-hinge larvae in the previous days.

All this is very different in the Knysna Lagoon. As there is no concentration of parent stock inside the lagoon—we only detected some isolated specimens on pillars of bridges and wharfs—we did not expect great concentrations of larvae at low tide when the water from the central part of the lagoon—where very few *Crassostrea margaritacea* live—flows down to the sea. Plankton investigations revealed that very few oyster larvae indeed are to be found in the lagoon at low tide. At high tide, on the other hand, considerable numbers of larvae may be observed, especially in the area close to the entrance of the lagoon. Evidently these larvae come from the sea. Great numbers of oyster larvae collected during a short tow-netting in the surface layers at the very entrance of the Heads, and the finding of larvae about 2 miles offshore on February 18th, corroborate that the larvae of *Crassostrea margaritacea* may be plentiful along the coast in the sea itself. Evidently these larvae originate from the countless numbers of parent oysters attached to the rocks along the coast. As larvae in all developmental stages were observed, all of them apparently in perfect health, it is obvious that they can develop normally in waters of a salinity of 34 to 35‰, and with temperatures of 22° to 24°C. We need not accept Ranson's hypothetical transportation of larvae from far-away Madagascar, and cannot possibly explain the presence of larvae a few days old in such terms. If larval development fails because of inadequate physical or chemical conditions it is particularly the development in the first 48 hours that is affected.

It is obvious, however, that the larvae observed in the downriver section of the lagoon at high tide, and leaving again with the ebb, have little if any, chance of returning to the lagoon with the next flood, for the water they live in is meanwhile displaced by the currents. As the oysters occur rather patchily along the coast, and as spawning of oysters always shows marked maxima and minima, oyster larvae will not be evenly distributed in the inshore water. We must therefore expect rather considerable day to day fluctuations in the number of oyster larvae entering the Knysna Lagoon. This is indeed what our observations show. Further, it is very noteworthy that we found on some days rather high percentages of "mature" larvae, ready to settle, but not preceded by commensurate numbers of "umbo" larvae on the foregoing days. Evidently these larvae had been developing in the coastal water for several days before they reached the Knysna area. There is every reason to consider the counter-current close inshore, flowing in a West-East direction (Isaac, 1937), as the main bearer of oyster larvae. Probably most of the larvae settling in the Knysna Lagoon come from a parent stock west of Knysna, maybe from the Mossel Bay district, since olden times renowned for its oysters. Plankton observations corroborate this view, for we found more than just oyster larvae in our samples. It was a plankton in which the zooplankton element predominated largely over the phytoplankton. Still, there evidently was enough food for the zooplankton, but all phytoplanktonic organisms smaller than about $60\ \mu$ passed through the meshes of our nets. In the zooplankton I found a variety of larvae of benthic invertebrates: swarms of lamellibranch larvae—among which those of *Teredo* and *Anomia* were readily identified—many Gastropod larvae, a variety of Echinoderm larvae, barnacle larvae, polychaete larvae, and so on. But even several of the copepods were later recognized by Dr. Vervoort as being typical neritic species. Evidently such a plankton can only be expected in rather shallow inshore water bathing a variety of benthic invertebrates. We could even expect considerable quantitative differences within the counter-current, depending on the parent stocks the bodies of water met on their paths. On February 18th we found fewer oyster larvae 2 miles offshore than closer inshore, but this evidence is not sufficient on which to base conclusions. The true Agulhas water, which according to Isaac is to be found only several miles out at sea, and the warmer topmost layers of which have not been in touch with benthic communities for a very long time, would never bear such great numbers of larvae of bottom invertebrates as the water of the

counter-current flowing so closely inshore in an opposite direction. Of course these waters are not always neatly separated, and especially if strong winds spring up there will be considerable mixing, whereby invertebrate larvae will be transported offshore, and will never find a suitable habitat on which to settle. This factor too will account for rather capricious fluctuations in the number of oyster larvae washed into the Knysna Lagoon, and will render it extremely difficult to build up a system of prediction of oyster settling based on plankton observations as reliable as that practised in the Dutch waters.

From our observations in the first few months of 1953 and from Van Dort's earlier experience with tile collectors we do, however, conclude tentatively that the best settling of *Crassostrea margaritacea* is to be expected from mid-January to about the end of February or early March.

It is not only an occasional offshore transportation of concentrations of oyster larvae that may account for sudden decreases in the settling prospects, for there is also the phenomenon of "cold water", discussed in an earlier section, which may interfere seriously. When the cold water came in on February 22nd, 1953, it drove away the warm water with its plankton. Evidently no further oyster spawning took place as long as the cold water persisted, for no larvae of *Crassostrea margaritacea* were detected in the samples taken from February 23rd up to March 5th. My departure made it impossible to continue the sampling after that date, but as Mr. van Dort informed me that the cold water persisted unusually long, and that collectors placed late in February failed to collect any oyster spat, it seems reasonable to assume that the cold water brought an abrupt termination to the South African oyster's season of reproduction early in 1953. It now occurs to me that the cold water may also have been responsible for the scantiness of oyster larvae in the first few days of sampling. There had been a short period of cold water just prior to my arrival at Knysna, and this may have swept away all the oyster larvae. Normal conditions were only gradually restored and "mature" larvae, ready to settle, were not observed before the last few days of January.

Another striking phenomenon was the conspicuous scarcity of oyster larvae at low tide in the downriver section of the lagoon, and at any phase of the tide higher up in the estuary. One would have expected that at least some of the larvae carried into the lagoon with each flood would become trapped there, and could be found in samples collected at low tide or in the area above

the railway bridge. The few oyster larvae we did find in such samples (2 low-tide samples on January 26th, 1 low-tide sample at Thesen's wharf on January 29th, the sample taken at half ebb in the dead corner in the S.W. part of the downriver section of the lagoon, and 2 samples taken in the central part of the lagoon on February 12th and 13th) invariably showed a striking loss of their once so bright colour, a loss of transparency and often the appearance of large hyaline spots in their bodies. Moreover, these larvae were virtually motionless; several others were dead. The same held good for several other types of marine lamelli-branch larvae encountered in these samples. That this phenomenon, only to be observed when living plankton samples are examined, should not be ascribed to changes after sampling, follows from the perfect condition, liveliness, and bright colour shown by Copepods—always the first to suffer from lack of oxygen—and by the larvae of the lamelli-branch *Modiola capensis*, of which thousands were found in the samples taken from the central part of the lagoon. It is as if oyster larvae and the larvae of some other marine bivalves cannot thrive in the rich greenish water of the central part of the lagoon. This can hardly be ascribed to the slightly lower salinity of this water. I have, however, witnessed this very same phenomenon before, and under very similar conditions. There is a cove at the upper end of the Oosterschelde, called the Eendracht, which contains water of the very same salinity, temperature, and oxygen content as is present in the basin of the Oosterschelde. Its water is, however, somewhat greener and richer—due to eutrophication—as shown by the greater number of small nannoplanktonic flagellates we counted there repeatedly. Oyster larvae are washed into this cove with the flood, and some of these become trapped there. Then they invariably lose their bright colour, develop large hyaline spots, and die, though the local conditions apparently appeal to a variety of other organisms. This very same thing happens often in tank breeding experiments (Korringa, 1951). It is as if a too-rich nannoplankton is not suitable for oyster larvae and to several other delicate organisms. Older oysters, including spat a few weeks old, do not seem to suffer at all in such water. I ascribe this phenomenon tentatively to the influence of certain organic excretates of the nannoplankton, for it is also evident during the early development of lamelli-branch eggs (*Ostrea*, *Venus*, *Mytilus*) before the food factor comes into the picture. I presume that the ever-failing development of oyster larvae

in the rich water of the Etang de Thau (Mediterranean coast of France) and in the Mar Piccolo (Southern Italy, Cerruti, 1941) should be ascribed to the same cause.

However this may be, we may rest assured that the rich greenish eutrophic water of the central part of the Knysna Lagoon does not appeal to the larvae of *Crassostrea margaritacea*, and that it should not be expected that the building up in this district of a fair population of adult oysters of any species will ever lead to the development and settling of larvae there. The Knysna oyster industry should receive its oyster larvae from the sea, and not from the central part of the lagoon.

One may wonder why I deal only with the larvae of *Crassostrea margaritacea*, and not with those of *Ostrea algoensis* and *Ostrea atherstonei*, which also settle on the collectors placed in Featherbed Bay, and which therefore must also occur in the plankton. The absence of parent stocks inside the lagoon makes it very probable that the larvae of these oysters too are washed in from the counter-current water with the flood tide. Though I searched for *Ostrea* larvae, which would not be hard to recognize, I only found very few, viz. on February 10th: 12 straight-hinge larvae measuring from 150 to 170 μ ; on February 12th: 1 larva of 140 μ ; on February 16th: 3 larvae of 150 to 160 μ in Keurbooms Lagoon; and on February 17th: 2 larvae of 150 to 160 μ in Sedgfield Lagoon. Evidently the season for reproduction of the *Ostrea* oysters had virtually ceased before mid-January. This was corroborated by the absence of "black-sick" *Ostrea algoensis* in that period, and by the fact that collectors placed in the second part of January or later caught spat of *Crassostrea margaritacea* only. Those placed in December, on the other hand, received *Ostrea* oysters only, among which *Ostrea algoensis*, the weed-oyster, largely predominated.

This difference in season of reproduction between *Ostrea* oysters and *Crassostrea* oysters tallies very well with the experience gained in other oyster districts where the two types occur simultaneously. In the Basin of Arcachon (Southern France, Atlantic coast) *Ostrea edulis* settles late in June or early in July and *Crassostrea angulata*, on the other hand, late in July or early in August. By a proper timing of the placing of the collectors the Arcachon oyster-farmers concentrate on catching spat either of flat oysters or of the Portuguese oyster. In the Puget Sound area and in Willapa Bay (Washington, U.S.A.), *Ostrea lurida* invariably settles much earlier in the season than *Crassostrea gigas*, and in

Japan *Ostrea rivularis* settles in early summer and *Crassostrea gigas* in late summer (Woelke, 1952).

Fortunately this phenomenon makes it possible to concentrate on the collection of the desired species of oyster in Knysna too. In placing tiles early in the season (December, early January), it will be predominantly the "weed-oyster", *Ostrea algoensis*, which settles. On collectors placed late in the season (late in January, February, perhaps early March) the common South African oyster, *Crassostrea margaritacea*, will be caught.

10.—SPAT COLLECTION AND THE REARING OF YOUNG OYSTERS TO MARKETABLE SIZE.

Coincidence of a variety of conditions is characteristic for outstanding spat collection locations. It is obvious that fair numbers of oyster larvae ready to settle should occur there either permanently or intermittently. As oyster larvae cannot possibly settle when there is a strong current, there must be prolonged periods of slack water at the spat collection stations, coinciding with the presence of the "mature" oyster larvae. Eddies are specially helpful in this respect, for they constantly bring in new larvae from the main body of water and may ensure low current velocities for hours in succession. Further, the location selected should not be so rough that artificial collectors cannot be kept there, and bottom conditions must be such that some type of collector can be placed in reasonable numbers at low tide spring level. A gently sloping bank with a hard subsoil is to be preferred. Other bottoms may be suitable too, provided the type of collector chosen matches the conditions. The type of collector should also be adapted to local economic and social conditions.

Van Dort was fortunate enough to find by empirical means a good type of collector and the best site for spat collection. It was soon clear to him that the cheapest way to collect oyster spat, viz. the scattering of molluscan shells of any description on a non-shifting and well-protected hard bottom, could not be applied here, for lack of such bottom and for want of adequate supplies of shells. The type of tile collector used in France and Holland not being available at Knysna, Van Dort selected the locally available asbestos roofing tiles. Discarded, slightly damaged tiles are to be preferred because of their low price. The approved European style of lime coating (a hard well-adhering layer underneath and a softer readily

detachable layer on top) was applied with success. Every brand of lime having its peculiarities, it always takes some time to find the correct mixture of lime, sand and water so that the topmost coating will not scale off by itself, but is soft enough to make it possible to detach the young spat undamaged. Other types of collector have been tried on an experimental scale by Van Dort, e.g. brushwood, tins on poles and scrap tin, but were found much less satisfactory than lime-coated tiles. When I saw the strong tidal currents in the Knysna Lagoon, I was not surprised that brushwood and scrap tin were unsatisfactory collectors there.

In the European oyster districts tiles are either placed in rows, the one leaning against the other, or bundled with iron wire and kept off the bottom on poles; in other cases they are stacked in crudely-made wooden crates. The bottom being liable to shift, Van Dort found it practicable to place the tiles, leaning against each other at an angle of about 60°, on some scrap board discarded by the local saw mill. The rows were placed at right angles to the coastline, and at about low water spring level (see Plate XIX, Figs. 1 and 2).

On my advice Van Dort placed experimental tiles in a variety of places inside the Knysna Lagoon during the first phase of the venture. He soon found out that the western shore of the downriver section of the lagoon yielded by far the best results, in particular the location known as Featherbed Bay (see Plate XIX, Figs. 1 and 2). Further, that as a rule the under sides of the tiles, not being exposed to silting, collected a greater number of spat than the upper sides.

The practical experience gained by Van Dort tallies very well with the results of our plankton investigations. As the larvae come into the lagoon from the sea, it is clear that the largest number of "mature" larvae, ready to settle, occurs in the downriver section of the lagoon, and in particular along the rather steep western shores, facing the main current. The closer they are to the sea, the longer a great number of larvae may be present there. In the bight at Featherbed Bay eddies can be observed along the shore during many hours a day. Therefore this site is excellent for spat collection, both from a theoretical and from a practical point of view. There is every reason to concentrate spat collecting operations in this area (see Plate III), and to omit any experimental spat collection in the area above the Knysna railway bridge and far inside the shallow inlets of the downriver section, in which too little ocean water penetrates on a normal tide.

The numbers of spat attaching to tile collectors placed in the best part of the season are certainly sufficient from a commercial point of view. The numbers of "mature" larvae of the South African oyster I counted in 100 litres of water in the best weeks early in 1953, are rather larger than those occurring during the height of the season in the Oosterschelde, Holland. Evidently the potential settling conditions are excellent in the Knysna Lagoon. By means of proper timing of the placing of collectors (in which plankton investigations can be of assistance, though with a smaller degree of accuracy than elsewhere for the reasons discussed above), it may be possible to step up the number of spat collected per tile. Perhaps this number could be increased also by adjusting the angle at which the collectors are placed (the vertical position is the least suitable for oyster larvae, but the best for avoiding silt and sand in the spaces which are left between the tiles for "entry" of the larvae and also for breaking the current). Of importance also is the direction in which the rows of tiles are placed: in Holland the best results are obtained when the rows are parallel with the main current.

However, no matter how favourable the spat collection operations developed in the Knysna Lagoon, may be, the next phase, the rearing of the spat, offers greater difficulties. Detaching the spat from the tiles at an early phase is often practised in European oyster regions, especially where good facilities exist to grow them to seed oyster size. The newly-detached spat, measuring from 10 to 20 mm. in diameter, is sometimes scattered on a piece of hard bottom. This procedure often entails disappointment, however, as the tiny spat is easily smothered by sand and silt, and its fragile shells are too easily crushed by voracious crabs and other predators. Another system is rearing on trays covered by wire-netting, kept off the bottom in some well-protected site with a fairly strong tidal current rich in food. Sand grains should not perpetually bombard the young oysters in the trays, and waves should not throw the spat in the tray corners, thereby destroying the fragile young shell shoots over and over again. Where favourable conditions prevail growth may be so rapid in the trays, and the losses suffered may be so limited during the 4 to 5 months the young oysters are kept in them, that it more than compensates for the continuous depreciation of the expensive trays and the constant supervision, care, and work required. Repeated tar-coating and frequent exchange prolong the life of the trays, and constant "weeding" and thinning out promote the growth of the young oysters.

Tray cultivation of spat at Featherbed Bay led to rather poor results, partly because the spat of the "weed-oyster", which does not grow much under the best conditions, predominated. Through wave action the spat was continuously thrown into the corners of the trays, thereby hampering their growth and destroying the young shoots. Many "weed"-organisms, especially smotherers like red bait and the like, settled on the young oysters, which was detrimental for their growth and feeding. Drills, and some other oyster enemies, caused considerable damage in the trays. Evidently this place is too rough for this phase of the cultivation, and enemies are too numerous there.

Some other experiments, carried out in a type of dyke—a piece of tidal flat surrounded by low walls, emerging at low tide only—at the southern end of Thesen's Island, were not very encouraging either. It is my impression that here too the water was too rough and sand-laden during summer with its frequent strong south-easterly winds.

There are two ways out of the difficulties thus far encountered in rearing oyster spat on trays:—

- (1) Selection of better sites for the placing of trays; locations protected from strong winds and wave action, and bathed in an almost constant stream of water rich in food. The oyster basin constructed on Thesen's Island certainly offers adequate protection, but unless large volumes of water are pumped through continuously it cannot be expected that hundreds of thousands of young oysters can be grown there simultaneously. The present subdivision of this basin is very good since the zigzag course the current has to take ensures a proper water renewal in every section. It is often said that strong light hampers the oyster's growth. I am not sure that this is true, but if this is found to hold good in the shallow basin—evidenced by poorer growth in the topmost trays at equal current conditions—some shading should be applied.

Proper sheltering and adequate food conditions can also be expected in the central section of the lagoon, from the railway bridge to below the new road bridge under construction. The areas considered promising have been denoted on a chart (see Plate III), but only through experimenting can it be ascertained whether these sites are as good as they seem. Particularly the flanks of the channels could provide favourable conditions, provided the sites

selected are properly protected against the winds prevailing in summer. Unfortunately a considerable drawback in this section may be lack of supervision. Unwelcome intruders may cause damage here, unless sufficient material can be concentrated to render it practical and economical enough to station a watchman there. Also one has to face the fact that the continuous contra-current sailing required by low tide operations in this section demands much more engine-power than that now installed in Van Dort's barge.

- (2) When the required conditions for tray cultivation do not exist, or in case the use of trays is considered too expensive, a *biennial* system of tile operations may replace the usual *annual* system. In this case the spat is not detached at an early phase, but left on the tiles until large and strong enough to withstand the dangers of sand, silt and crabs without the protection afforded by wire-covered trays. Many of the Dutch oyster-farmers switched over to this system when the tray cultivation became more and more expensive in recent years because of an increase in wages and in the price of wire-netting galvanised before and after weaving, and because of a decreasing price of seed oysters. It is true of course that only half of the stock of tiles can be used for spat collecting each summer, the other half bearing spat one year old. Also that it is wise to use a somewhat harder lime-coating to prevent premature spontaneous falling off of the spat. Further, it is wise to transfer the tiles with spat to locations which are well protected against gales, sand, frost and predators, and, if possible, poor in smothering organisms and rich in food. Whenever smothering organisms have settled on the tiles and threaten to kill the oyster spat, it pays to destroy these organisms. Fortunately the young oysters are better protected against special treatment than the majority of the smothering organisms, which lack a shell to hide in. Bathing the tiles either in fresh water for about 16 hours, or in a solution of copper sulphate or corrosive sublimate (1 part per 15,000 for about 2 hours) will kill all the sponges, red bait, other ascidians and bryozoa without killing the young oysters. The latter will show surprisingly good growth after the treatment which has freed them of their competitors.

Considering the conditions prevailing at Knysna, it seems to me advisable to follow the same principle. It certainly will be cheaper to double the stock of tiles than to use a great number of small-meshed trays for the rearing of the spat. The downriver section of the lagoon is, however, characterized by a profuse settlement of a variety of smothering invertebrates and by the presence of drills, which may kill the young oysters. The closer to the Heads, the more serious the danger. Therefore it seems advisable to transfer the tiles to safer areas some time after settlement of the spat. In the area above the railway bridge drills may be absent, smothering organisms rare, food plentiful, and protection from bad weather adequate. Locations too rich in suspended sand, and those frequently bathed in river water should be avoided.

If the spat is taken off in its second spring it will have grown to a fair size, and possess a strong shell offering adequate protection against a variety of dangers. Wherever a large acreage of flat hard bottom is available, such oysters should be planted, together with oysters of similar age but reared in trays during their second summer. Such is the procedure in Holland, in most of the oyster districts in France and also in the oyster area of Prince Edward Island, Canada.

Suitable bottom for the planting of oysters has as yet not been found in the Knysna Lagoon. At most there are some places in the central part of the lagoon where we would advise a small scale experiment within a proper wire-netting or stake enclosure to keep off the musselcrackers. Bottom conditions are certainly not excellent here, and it is only because cultivation directly on the bottom is so much cheaper than any other method of cultivation that we encourage such experiments. But even in case the results obtained here are disappointing, there is no reason to abandon the oyster venture! For, there are very important oyster districts in the world where not one single oyster is grown directly on the bottom, and this not only in many districts of Japan, where labour is comparatively cheap, but also in Norway, in the Etang de Thau (Mediterranean coast of France), in Italy, in Yugoslavia, and in particular in Australia. Keeping oysters on trays until they have reached marketable size is possible—it is the regular procedure in the Norwegian oyster polls—but this is certainly a very expensive method, and the oysters thus grown often have a rather thin and sometimes somewhat irregular shell. In well-sheltered places with moderate or modest currents, hanging cultures can be practised, whereby half-grown oysters (seed oysters) are kept off the bottom

in water rich in food. The oyster trays are either cemented down to poles of hard *Teredo*-resistant wood, or fastened to rope or wire and next hung from a supporting frame (Etang de Thau, Italy and Yugoslavia), and in other cases rafts are used to support the ropes or wires carrying the oysters (Japan).

Considering the conditions prevailing at Knysna, the Australian system seems to be more promising and cheaper. The situation in some important Australian oyster districts is indeed so similar to that at Knysna, that the methods used there deserve the greatest attention. Information kindly given by the oyster-farmer Mr. A. Salm at Salt Ash, N.S.W., demonstrates that the lagoon-like estuary at Port Stephens, N.S.W., has a downriver section in which clear ocean water predominates, next a narrowing and then a central section, with some inlets, in which section rather turbid greenish-grey water can be found (see Plate XX). Next follow the true river mouths, receiving some brown river water, but saline in their deeper layers. Occasionally the river discharges larger volumes of fresh water. The oyster-farmers in this area have experienced that spat collection should be carried out in the downriver section of the lagoon, but that growth and fattening is much better in the central section, with its greenish water. As far as I am aware it has not yet been made clear by scientific investigations why oyster larvae abound in the outer area, but fail to settle in significant numbers in the central section of the lagoon, though millions of oysters grow there. Could it be that the water condition does not appeal to oyster larvae there or is transportation by currents the causative factor? Except for some small plots in the true river mouths, there is no bottom suitable for the planting of oysters. For spat collecting great numbers of lath racks are constructed and these are dipped in hot tar and next thoroughly dried in the air. Numbers of such racks are nailed down to strong wooden supports placed at low tide level in the downriver section of the lagoon at about the time the spat can be expected. The oyster spat of the local oyster (*Crassostrea commercialis* L. and R.) settles on the tarred surfaces of the racks. For further growth the racks are transferred to the central section of the lagoon, where they are nailed down to other supports, slightly above low water level. In the rougher and colder season, racks with spat may temporarily be stored in depots in a well-sheltered area. The oysters, still attached to the laths, are kept in the growing and fattening area until they are ready for the market. Those

which fall off during transfer and nailing operations are placed in trays for further growth. The deeper the level at which the oysters are kept, provided they are well off the muddy bottom, the better they grow and fatten; but sometimes a disease, locally called "opening disease" may strike, from which the oysters suffer less or more depending upon the higher or lower level at which they are kept.

As this system has been practised for years with great success commercially in an area strikingly resembling the Knysna Lagoon in its hydrology, and as it limits the use of expensive trays to a minimum, I would strongly recommend that a serious effort be made with this method at Knysna. It may happen that the local oyster spat may refuse to settle profusely on tarred surfaces, even when properly dried in sun and air, but in that case it would be possible to give the laths a hard lime coating before they are immersed. A tar undercoating is necessary to keep off *Teredo*, otherwise the laths would soon fall apart. In Australia too, some fishes cause havoc among the oysters. Coarse wire netting or stake fences around the racks keep off these fishes.

Even if it proves difficult to induce the larvae of the South African oyster to settle on lath collectors similar to those used in Australia, there is every reason to consider the possibility of rearing the yearling oysters to marketable size by means of a system similar to that used in Australia. It would then be necessary to fasten the oysters taken from the tiles in their second spring to some type of support. This could be wood of a type resistant to *Teredo*, and then a cement mixture could be used to fix the oysters. It will be advisable to put the cement on rough or slightly excavated places of the wood. The wood carrying the oysters could then be nailed down to racks similar to those used in Australia, here too in the richest section of the lagoon. Nailing should not be begun before the cement has completely set. Until that moment the laths can temporarily be stored in the oyster basin. If it is difficult to find or to make *Teredo*-resistant wood (e.g. by applying creosote under pressure), or to fasten oysters to well-tarred wood—either with a cement mixture or with thick tar, which should not be too hot when applied, or perhaps with some other type of glue able to withstand salt water—attempts could be made to cement oysters down to tiles and to develop a system of placing or hanging those tiles on racks in a suitable place. The losses may be surprisingly small with such a procedure.

II.—OYSTER ENEMIES AND THEIR CONTROL.

It is only natural that some losses are incurred on the long journey from tiny spat to marketable oyster, even when the hydrological factors leave nothing to be desired. For, oysters too have their natural enemies, both microscopical and macroscopical in size. The greater the concentration of organisms of any description, grown in monocultures, the greater the risk that the natural equilibrium may be disturbed by a sudden numerical increase in the number of predators or parasites. Oyster-farmers should be well aware of this danger and should take action whenever the losses suffered attain abnormal proportions. In the Knysna Lagoon one should keep an eye on the following organisms because they are potential oyster enemies:

(1) Drills.

A variety of gastropods, as a rule belonging to the families *Naticidae*, *Murecidae* or *Purpuridae*, feeds at least partly on lamellibranch molluscs, which they overpower by drilling a hole straight through their protective calcareous valves. This is why they are generally called "drills". Even large oysters may fall victim to drills, but as a rule the drills prefer to attack young oysters and spat. The losses among the oyster spat a few weeks or months old may be terrific where drills get a chance to build up a substantial population. Though the most notorious oyster drills *Urosalpinx cinerea* and *Tritonalia japonica* do not occur in South African waters, and though some other drills specialise on bivalves other than oysters or on barnacles, drills do kill oysters at Knysna. Especially among the tiny spat on tile collectors at Featherbed Bay we observed quite a few killed by drills, these were recognizable by a tiny round hole in the flat valve. Drills may also penetrate trays of oysters, but as yearling oysters constitute a more substantial meal than the tiny spat, serious damage is only to be expected when large numbers of drills enter. It is necessary to inspect tiles and trays at frequent intervals and to carry out control measures whenever necessary. When interchanging trays care should be taken to collect any drills that occur in or on the trays. Whenever great numbers of drilled oysters are detected one should try to track the hiding place of the culprits, and to destroy these, and at the same time search for their characteristic egg capsules which are attached to solid objects.

Damage among spat can be avoided by transferring the tiles to areas where drills do not occur, in

which procedure care should be taken to clear the tiles of drills and their egg-cases prior to transfer. The closer to the sea the greater the number and variety of drills, therefore the greater the risk that oyster spat will be lost through their activities.

(2) Fouling Organisms.

Though the lime-coated surfaces of tile collectors are destined for the settlement of oyster spat, it is hard to prevent organisms other than oysters also selecting this site for their sedentary existence. Among these may occur organisms which become so numerous that they take an appreciable part of the space destined for oysters. Others may grow so rapidly that they soon cover large patches, and smother the oyster spat in their vicinity. Several of these fouling organisms should also be considered as food competitors of the oyster.

It is my impression that the problem is not a very serious one at Knysna. There is, for instance, a peculiar tiny jingle shell (*Anomia* sp.) which settles in large numbers on the collectors and thus take up considerable space destined for the oyster. If it settles in January, it is already full of spawn in February at a diameter of 4 to 5 mm. only. In March, 1953, we found many dead. I wonder whether it was the cold water that killed them. I cannot believe that the life cycle was terminated so early, for this would require an incessant succession of new generations throughout the year. It is remarkable that we never found specimens over 5 mm. in diameter.

Further, there are barnacles, which are a serious nuisance in many oyster regions. Thus far the numbers settling on the collectors in Featherbed Bay have not been alarming. Many smothering organisms belong to the ascidians, sponges and bryozoa. Especially the red bait, *Pyura stolonifera*, may be found in great numbers. Whenever they threaten to smother appreciable numbers of spat, it is advisable to apply some measure of control. Scrubbing with a hard brush is not always efficient, since sufficient remains of sponges, bryozoa and composite ascidians (e.g. *Botryllus*) are left to allow rapid regeneration. It is better to kill them off completely by bathing the badly affected tiles in either fresh water (several hours) or some poisonous solution (corrosive sublimate or copper sulphate 1: 15,000, 1 to 2 hours). Dutch oyster-men sprinkle stronger solutions of either of these poisons between the rows of tile collectors, which procedure saves much labour. The oyster spat easily survives such treatments and will show excellent growth when freed from their competitors and smotherers. Such treatment is especially

advisable at the beginning of the colder season, because the recruitment of the smotherers will be modest in the months to come.

When the cleaned tiles are next transferred to an area higher up in the lagoon, it is very probable that fewer smothering organisms will settle on them from then onwards than in the case of tiles remaining at a station close to the mouth of the lagoon.

(3) Crabs.

In many an oyster district crabs are notorious pests. Particularly the single young oysters, attached to a tiny collector are vulnerable to the attacks of these voracious decapod crustaceans. Oyster spat attached with its entire left valve to a larger collector does not easily fall victim to crabs. When the spat has settled too close to the edge of the collector, the growing shell will soon protrude freely and then the crabs may crack off this protruding part of the shell, which often gives them access to the edible parts of the oyster.

Some large types of crabs (e.g. *Menippe*) have such powerful pincers that they can break the shell of adult oysters, but these crabs only occur in certain localities.

Crabs do occur at Knysna, but thus far they have not threatened the oyster venture seriously. While still growing on the collectors the young oyster seems almost invulnerable to the attack of crabs. There may be some damage in the trays, for the crabs may come in when they are still small enough to creep through the meshes of the wire-netting. When they find enough food in the trays they soon grow so much that it becomes impossible for them to crawl out again. The unwelcome intruders can be destroyed when the trays are interchanged.

In the upriver section of the Knysna Lagoon lives the famous edible Knysna crab, which lives in holes and is said to have nocturnal habits. Under the present conditions it will rarely if ever find oyster in its path. I have no information on the feeding habits of these large crabs, but the possibility remains that they may become harmful when oysters are grown on a fair scale close to their habitat. Oysters kept in trays will be almost invulnerable, but those which are more readily accessible could fall victim.

(4) Sea-urchins.

Van Dort has repeatedly found fair numbers of sea-urchins in his trays with oysters. As a rule they cling to oysters and seem to nibble at the thin edges of the oyster's shell. Evidently they come into the trays either as planktonic larvae or as very young benthic individuals, with a diameter

smaller than the size of the wire netting's meshes. The observation that sea-urchins nibble at the oyster's shell is no doubt correct. I have seen very similar things in the hanging mussel cultures of the Etang de Thau, France. I presume it is the lime they are after, since sea-urchins need lime to construct their shell, but cannot collect calcium ions in the same way filter feeders like oysters do, i.e. by catching them on their mucous feeding sheets.

Whenever sea-urchins become a pest at Knysna, they can either be collected from the trays by handpicking or be destroyed by some chemical method, as they cannot withdraw all their delicate tissues temporarily inside a safe shell, like the oyster. Bathing the infested oysters in a solution of copper sulphate or corrosive sublimate (e.g. 1: 15,000) will serve the purpose, but spreading of finely granular unslaked lime may also be found an efficient method of control.

(5) Flat Worms or Wafers.

Among the oysters at Featherbed Bay I saw several specimens of a small leaflike Polyclad worm. Though there is no immediate reason for concern, it is advisable to be distrustful of their presence, for similar "wafers" are reckoned among the oyster pests in some districts. Damage has been reported from Australia, Louisiana, Florida and Italy. However, it is hard to understand how those small flatworms can overpower oysters; but a short time ago Lindsay *et al.* (1953) reported that similar Polyclad worms can kill oyster spat and even yearling oysters by drilling a very tiny key-hole straight through the shells. Then the worm injects some sort of fluid through the hole which either separates the adductor muscle from the shell or causes paralysis of the muscle. The worm then enters and separates both muscle attachments from the shell, while the oyster is still alive (as evidenced by heartbeat, movements of the cilia, and water pumping) and next engulfs the entire oyster meat. It is claimed that a high percentage of the losses observed among the oyster spat in the region under consideration (Puget Sound, Washington, U.S.A.) can be ascribed to the activities of these Polyclad worms.

(6) *Polydora*.

Polychaete worms of the genus *Polydora* are reckoned among the oyster's enemies. These organisms make their burrows in the oyster's shell and are only a nuisance when there are many, since the shell becomes brittle, and the oyster is irritated by repeated shell perforations. Other types of *Polydora* crawl in between the shell and the mantle of the oyster and collect considerable

quantities of mud there. The oyster always tries to seal off the mud with calcareous deposits. Disfiguring mud-blisters on the shell's interior surface are the result. The formation of mud-blisters reduces the volume of the shell cavity and forces the oyster to devote much more of its energy to shell secretion than would otherwise have been necessary. Therefore, heavily infected oysters are often in poor and watery condition. Oysters with fewer mud-blisters may still be in reasonably good condition, but the opened mud-blister oysters have an unpleasant appearance and are commercially not readily saleable.

Mud-blister *Polydora* occur in the Knysna area. In the experimental enclosure for trays at Greenhole (c.f. Plate III) we found some batches of oysters which had been heavily attacked by *Polydora* and hence were in poor condition. It will be wise to avoid stations where *Polydora* occurs too frequently. If medium or heavy infestations are observed, it pays to kill the *Polydora* by bathing the oysters for about 16 hours in fresh water, if necessary repeatedly. Such oysters, freed of their enemies, recover soon, and will lay down sufficient calcareous matter on the blisters to make these invisible to the consumer.

(7) Sea-cats.

The sea-cat or *Octopus* occurs frequently at Knysna, and oysters certainly are an item of their diet if they can get hold of them. Their burrows were often lined with oyster shells in the former Slavlei enclosure. They will not, however, take spat from the collectors, nor oysters out of a tray. It remains to be demonstrated whether they can overpower large oysters attached with their entire shell to some flat support.

Their hiding among the tile collectors at Featherbed Bay would therefore not be alarming, were it not that local fisherman detected this habitat and tried to catch their favourite bait by turning over the tiles, which are often left behind flat on sand and mud. This may lead to serious losses among the oysters. If arrangements for a permanent watchman at Featherbed Bay cannot be made, the sea-cat should be considered an indirect enemy of the Knysna oyster industry.

(8) Prawns or Kappers.

From the time Van Dort started searching for suitable bottom for the relaying of oysters in the Knysna Lagoon, he was worried by the enormous numbers of burrowing prawns (*Callianassidae*) in this area. In the sandy type of soil are found the deep burrows of *Callianassa kraussi* Stebb., and

in finer deposits, including the eelgrass fields, it is *Upogebia africana* (Ortm.) which abounds (see Plate IV, Fig. 1). The latter species is so prevalent in almost any area where the bottom seems stable and deep enough for the planting of oysters, that the soil is actually honey-combed by their burrows. Any oysters planted there run the risk of becoming smothered with the excavated material.

My own observations certainly confirm this view. The mud-prawns are permanently busy excavating their burrows and consequently oysters, especially young ones, are easily smothered by the material thrown up in the process of excavation. We did not find an appreciable acreage of stable, non-shifting bottom of sufficient depth devoid of *Callianassidae*. This makes planting of oysters very hazardous indeed.

Callianassidae are not frequently mentioned as oyster pests. They are, however, a nuisance in the Puget Sound area (Stevens 1928, 1929). *Upogebia pugettensis* (Dana), the worst oyster enemy there, prefers muddy bottom rich in gravel, but avoids the *Zostera* fields. In this respect *Upogebia africana* differs, for this species is usually found in sandy muds, including the eelgrass fields. Both large-scale smothering of oysters and the undermining of the low walls keeping the water within the dikes in which oysters are grown in the Puget Sound area, are blamed on the *Callianassidae*. The most effective defence which has been developed there is a double board floor (the second rectangular on the first), covered by a thin layer of sand and gravel. Evidently the initial expenses are so large in this procedure that it is almost prohibitive to apply it on a large scale.

When it is established that other systems of rearing are more practical in the Knysna area than the planting of oysters directly on the bottom, the prawns will not be the main headache of the oyster-farmer.

(9) Musselcrackers.

As was reported in one of the introductory chapters, Van Dort soon found out that oysters planted directly on the bottom may be destroyed by large fishes, locally called musselcrackers (*Sparodon durbanensis*, see Plate II). With their powerful jaws they crush thick oyster shells and they finish off the last oyster. Similar happenings in several of the French and Australian oyster districts led to the development of a practical method to prevent such damage. By placing a fence of stakes or of coarsely-meshed iron wire netting around the planted area, oyster-eating fishes can be kept out of the enclosure. Such measures are not only required when oysters are planted on the

bottom, but are also advisable in places where oysters attached to laths or tiles are grown to marketable size. The expenses are more than compensated for by the marked reduction in the losses suffered through the voracity of fishes.

12.—DIFFICULTIES ENCOUNTERED IN REARING *OSTREA EDULIS*, THE EUROPEAN FLAT OYSTER.

It was puzzling why the first consignment of European oysters kept on trays in Featherbed Bay developed so well, in sharp contrast to the consignment sent the next year, which showed very poor growth and poor condition. Still, the quality of the oysters shipped left nothing to be desired, losses during transit were negligible, and other conditions were kept as close as possible to those in the first year. As it was also observed that the oysters which grew so well the first year retarded their growth considerably the next summer, it was evident that some adverse condition interfered with their well-being.

From the information given by Van Dort, after examining samples of oysters shipped to Holland, and from inspection on the spot early in the year 1953, I concluded that it was not one of the oyster enemies listed above that could primarily be held responsible for the poor growth of *Ostrea edulis* at Knysna. Neither can it have been a general lack of food in the second year, for a few Portuguese oysters occurring incidentally among the flat oysters developed remarkably well in the same trays, and specimens of *Anomia ephippium*, a jingle shell, attached to some of the flat oysters imported from France and also gaining a livelihood by filtering off the water, grew so well that their diameters soon exceeded by far those of the oysters they had settled on. This never happens in places where the oysters grow satisfactorily.

Ostrea edulis is rather particular about its habitat and it may also suffer from microscopic parasites or diseases. Adult oysters, especially when grown in overpopulated areas, suffer more easily from such parasites than spat and yearling oysters. As it was the latter category that was flown out to Knysna after a careful selection and inspection, I did not consider it very probable that either parasites or some other type of disease could be held responsible for the failure, the more so as this area was new for the species.

An interesting experiment corroborated this view. Some of the oysters which grew so poorly in the trays at Featherbed Bay were transported in September, 1952, to Saldanha Bay and placed on a tray there in a well-sheltered site at Langebaan;

this tray was under the supervision of Mr. J. D. Allen, Director of the Pearl Oyster Shell Industry Pty., Ltd. It is our experience that oysters seriously attacked by microscopic parasites or diseases seldom or never recover completely. When we inspected the tray of oysters on March 9th, 1953, we found to our surprise that the flat oysters, *Ostrea edulis*, had recovered marvellously. Even shell growth had been resumed, and the edible parts were certainly in perfect condition, showing a digestive gland of dark brown colour. This was in sharp contrast to the lean watery condition and yellowish digestive gland in the oysters which remained at Featherbed Bay. It is very interesting to note here that young oysters of other species had also been transferred to Saldanha Bay simultaneously with the specimens of *Ostrea edulis*. Of these both the Portuguese oyster (*Crassostrea angulata*) and the red oyster (*Ostrea atherstonei*) grew very satisfactorily in the few months of sojourn at Langebaan (see Plate XV, Fig. 1). Young specimens of the "weed" oyster, *Ostrea algoensis*, on the other hand, though apparently in good condition, showed very little growth. This corroborates our view that *Ostrea algoensis* is a very slow grower, of no interest to the oyster industry.

From our experience with the fussy *Ostrea edulis* I tentatively conclude that it was neither enemies nor parasites that led to the failure at Knysna, but that some factor of the physical environment must have prevented the oysters from collecting sufficient food. I surmise that suspended sand, perpetually bombarding the oyster's delicate tissues, and possibly also choking its filtering mechanism, could be blamed. The Dutch oyster-farmers know too well that "sharp" bottoms, where the tides sweep along thousands of sand grains yield poorly growing and lean oysters, though the water in which the latter are bathed contain food in abundance. In collecting plankton samples at Featherbed Bay I was amazed to see how much sand was suspended in the water there. This tallies with Van Dort's observation that the water was often "thick" with sand at Featherbed Bay, especially when the south-easter was blowing. Obviously flat oysters kept in this windward station starve in the midst of plenty because too much suspended sand interferes with their feeding.

That *Ostrea edulis* grew well the first time, but very poorly the next summer is readily explained by Van Dort's information that the former summer was an unusually calm one and the latter a summer with frequent strong south-easterly winds, which unfavourably affected the ecological conditions in completely exposed sites such as Featherbed Bay.

If it should be decided to carry out any further experiments with *Ostrea edulis*, it is obvious that well-sheltered stations should be selected, where plenty of water rich in food, but poor in inedible suspended matter arrives with the tides.

13.—ECONOMIC ASPECTS OF OYSTER CULTIVATION AT KNYSNA.

Having described the life of the oysters at Knysna in the foregoing sections, it is well to pay some attention to the economic aspects of oyster cultivation in the Knysna Lagoon.

In the earliest phase of the venture at Knysna, I warned the late Mr. Bright repeatedly that oyster culture was not a kind of manufacture leading to quick results simply because some basic requirements had been provided, but that it is a true cultivation that should be carefully adapted to local conditions, and that it is only after a lengthy experimental phase that cultivation may become remunerative. Though much valuable experience has been gained, the hazards of the experimental phase, discussed above, are not yet completely over, and it is still too early to say that the Knysna oyster industry has established its methods in such a way that the remunerative period has begun. It is as well to try and give an unbiased answer to the question whether the experience gained thus far gives sufficient hope for favourable future development of the Knysna oyster industry, and whether the starting point, the idea that there is a place, if not a need, for cultivated oysters in the Union, still holds good.

To begin with the latter question, we can state that the Knysna Oyster Company has experienced that there is a good demand for oysters in the cities of the Union, a demand exceeding by far the quantities of oysters which can at this time be offered for sale. Well-graded, well-packed, and quickly-despatched oysters of good quality are well received on the South African market, and it would take little advertising to increase the demand still further. When a larger public gets used to the well-flavoured South African oysters, and learns that these are treated by experts with all possible care, so that it is always perfectly safe to order and consume these oysters, the demand will no doubt increase steadily. Very important points are that the marketable oysters should always be young and tender, of equal size and quality, and always readily obtainable in the quantities ordered at the specified time. Even the best market will be ruined by a supply too irregular both in quantity and quality. Oysters picked from the rocks, provided they are well graded and kept in a suitable and reliable basin for some time, can be used to meet the present demand to some extent. Weather

conditions and tides have an enormous influence on the number of oysters that can thus be harvested, and it may often happen that the supply in the Knysna storage basin gets exhausted in the middle of the oyster season. Further, the more easily attainable oysters will sooner or later decrease in numbers in the areas readily reached by motor transport. All this indicates that the only way to step up the sale of oysters and to stabilize the market already developed is the cultivation of oysters. As it is our opinion that a good business should be able to offer oysters in a variety of grades and at a variety of prices any day of the season, and that a business that has frequently to refuse supply to regular customers will sooner or later fade away, only the cultivation of oysters provides an adequate solution for the situation.

By means of the cultivation of oysters it is possible to supplement the supply of wild oysters taken from the rocks (see Plate XXI, Fig. 1), and bring to the market oysters of regular shape and size with good-quality meat. It is very important to decide which type of oyster should be used for cultivation. As the South African public is already accustomed to the appearance and the outstanding flavour of the common South African oyster, *Crassostrea margaritacea*, it seems logical to try to cultivate this species, which is no doubt perfectly adapted to the local ecological conditions. There is indeed every reason to concentrate on the cultivation of this oyster, but unfortunately one has as yet no definite proof that it has all the qualities a good cultivated oyster should possess. It is possible to collect sufficient numbers of spat of this oyster, provided the collectors are placed in the second half of the summer season (later than January 15th), and provided prolonged periods of cold water do not seriously interfere with its reproduction. As has been described above, the spat caught in the earliest phase of the venture was lost through unfortunate incidents, and in later years tiles were placed too early to catch large numbers of spat of this oyster. Therefore we have not as yet sufficient evidence on the number of years this oyster requires to develop a size and quality adequate for marketing. If too many years are involved it will be hard to make its cultivation pay. There are, fortunately, several indications that this oyster is not a poor grower, and, if the proper methods of cultivation are selected, that it will be possible to grow it in great numbers. Of the various systems of oyster cultivation the methods used in Australia seem very well adapted to conditions at Knysna, and will render it unnecessary to use large numbers of trays for prolonged periods. A great advantage of this oyster is that apparently it can cope with sand-laden

waters, for specimens attached to the rocks in the surf of sandy beaches are almost invariably in perfect condition.

The so-called "weed oyster", *Ostrea algoensis*, settling in large numbers early in the summer season (December and first half of January) should be avoided, as it is a poor grower that will not reach a fair size within a reasonably short time. It seems improbable that the South African public will develop a taste for this small oyster because of its different flavour, for the common South African oyster has a flavour which is hard to beat.

A very promising oyster is the red oyster, *Ostrea atherstonei*. It has a very good flavour and seems to attain marketable size within a short time, which is an outstanding quality for a cultivated oyster. Unfortunately, at the present time, it seems very difficult to collect this oyster in commercial numbers, but it would certainly be interesting to follow the hints I gave in an earlier section, for it may be possible that it settles in reasonable numbers on some other part of the coast (e.g. Keurbooms Lagoon or False Bay).

The experiments with European oysters, undertaken in the early phase of the venture before it was known that indigenous oysters would settle on artificial collectors in numbers of commercial significance, led to the conclusion that *Ostrea edulis*, the famous European flat oyster, did not find conditions to its taste in the experimental site selected. It can, however, grow normally in some South African waters (compare Langebaan, Saldanha Bay, experiment). There seems very little hope that suitable bottom will be found in the Knysna Lagoon on which this rather exacting oyster can be planted. Use of trays or some other type of support is therefore imperative.

The Portuguese oyster, on the other hand, which is known to be much hardier than *Ostrea edulis* and grows faster too, evidently does very well in the Knysna Lagoon. Until the common South African oyster, *Crassostrea margaritacea*, has shown good rearing qualities in every respect, I would advise the continued rearing of the Portuguese oyster, transported to the Union as yearling oysters in the cool-chamber of a fast ship. Thus, at short notice it is possible to produce a reasonable quantity of oysters of good quality. Growth of the Portuguese oyster has thus far been extremely good at Knysna, better than in most places in Europe. Its edible parts become fatter here than practically anywhere in France, and the flavour developed is good, though differing noticeably from that of the common South African oyster. It is true that no place has as yet been found where this oyster can safely be planted on the bottom, but now that trays are used for cultivation, it is

the short time taken by Portuguese oysters to attain marketable size that makes this species very attractive. We should add that it may very well be possible to develop cheaper methods of cultivation, and that the Australian system, or an adaptation of it, seems rather promising. We should not forget to mention three points that might be raised against the cultivation of Portuguese oysters. First its taste is so different from that of the common South African oyster that the public will no doubt notice it; and though billions of Portuguese oysters are yearly consumed in France, and though many a Frenchman even prefers this oyster ("les véritables huîtres de la mer") above the flat oyster, the preferences of an exacting public are a rather capricious and unpredictable matter, and are hard to guide. I trust, however, that by means of expert salesmanship it will be possible to overcome the first difficulties and make the South African public acquainted with this different but excellent sea food. The second point is that in the event of the Portuguese oyster showing via its rapid growth so great an advantage over the common South African oyster that it is decided to concentrate on cultivation of the Portuguese oyster only, it will not be an easy matter to produce sufficient spat of the species at Knysna. Reproduction of Portuguese oysters is successful in a few locations only in Europe. In other places growth and fattening may be excellent, but reproduction may fail repeatedly. It is certainly not impossible that this oyster may reproduce well in some bay or inlet along the South African coast, but until that spot has been found it will be necessary to import the yearling oysters from Europe at frequent intervals. The third point is that the Portuguese oyster seems to be much more vulnerable to the attack of mud-blister *Polydora* than the common South African oyster.

14.—PRELIMINARY NOTES ON SOME OTHER SOUTH AFRICAN WATERS IN RELATION TO THEIR SUITABILITY FOR OYSTER CULTIVATION.

Though most of the time I could spend in the Union was devoted to studying ostreological conditions in the Knysna Lagoon, some other lagoons and inlets were surveyed superficially to find out whether or not favourable conditions for oyster culture might exist there.

(a) Keurbooms Lagoon.

At the western side of the mouth of the Keurbooms River there is a bag-shaped widening called Keurbooms Lagoon (see Plate X). This lagoon is isolated at low tide and in communication with

both the sea and the river for a few hours at high tide. At the time of our visit (16/2/1953) it contained water of high salinity (33.2^0_{00}), and its colour also indicated that only a little river water reaches this lagoon under normal conditions. The brownish river water collected at the mouth of the Keurbooms River shortly before low tide (16/2/1953) had a salinity of 27.9^0_{00} , and even as far inland as the Old Drift in the Bitou River (see Plate X) the salinity of the bottom layers was as high as 13.4^0_{00} . It is said that during floods of the river the water in the lagoon may become rather brown and brackish. Since there is no large upriver mixing basin, like in the Knysna Lagoon, it seems reasonable to suppose that rather abrupt salinity changes may occur in the lagoon when the river floods. The bottom is sandy and mainly covered with eelgrass (*Zostera*), and therefore not inviting for the planting of oysters. Our preliminary conclusion is that the Keurbooms Lagoon does not seem to be very attractive to the oyster-farmer. But since the interesting red oyster (*Ostrea atherstonei*) settles there in appreciable numbers on *Pinna* shells, it would be interesting to place some test collectors there at intervals of about a fortnight in the first part of the summer season.

It should also be interesting to place some trays with Portuguese oysters in this lagoon, for it is our impression that there is, as at Knysna, sufficient food in the lagoon. Any larvae produced by the Portuguese oysters might find conditions to their taste here. If so, the limited dimensions of the lagoon may set bounds to the dispersion of the larvae so that there may be a better chance for reasonable numbers of them to become attached to collectors placed at the appropriate time, than is the case in the Knysna Lagoon.

Analysis of a sample of water from the Keurbooms Lagoon, taken in its centre on February 16th, 1953, at about an hour before low tide, yielded the following figures:—

Station.....	Keurbooms Lagoon, central part, 30 cm. under surface.
Date.....	16/2/1953
Tide.....	1 hour before low water.
Salinity.....	33.2^0_{00}
P. mg. atom/m ³	0.25
Organic matter (mg. KMnO ₄ /l)	7.4

These figures do not differ noticeably from those (under similar conditions) in the Knysna Lagoon. A tow with a 70 μ meshed plankton net yielded

3 larvae of an *Ostrea* oyster and a great number of larvae of other marine lamellibranchs (excluding *Crassostrea margaritacea*), and also of gastropods; further many small Crustaceans and a few *Pleurosigma*-like diatoms.

(b) Groenvlei or Lake Pleasant.

Due west of the Knysna valley is situated a landlocked body of water called Groenvlei, with a surface considerably above sea level (see Plate X). The water appears to be nearly fresh at the surface and also in the deeper layers. This is so all the year round. Fresh-water vegetation is to be found on the bottom. At the time of our visit an evil-smelling type of *Chara* predominated. The water had a milky green colour; according to local residents this colour had persisted for several years in succession. It was said that the water had been clear at an earlier period. The very low salinity prohibits oyster experiments in this lake.

Analysis of a sample collected on 25/2/1953 yielded the following figures:—

Station.....	Groenvlei or Lake Pleasant	
Date.....	25/2/1953	
Temperature.....	Surface. 26.0° C.	Near bottom 25.0° C.
Salinity.....	Surface. 1.0 ⁰ / ₀₀	Near bottom. 1.0 ⁰ / ₀₀
P. mg. atom/m ³	Surface. 0.28	Near bottom. 0.32
Pigment— Filter No. 366.....	430m μ 2.0	670m μ 9.4
Organic matter (mg. KMnO ₄ /l).....	Surface. 50.6	Near bottom. 49.1

From these data it can be concluded that the quantity of organic matter is very much higher than anywhere in the Knysna Lagoon or in offshore waters. The true nature of this organic matter is not known. At the place of sampling we found no trace of pollution. A surface tow with a 70 μ plankton net yielded very few organisms. Phytoplanktonic organisms were not caught. Observations with a haemocytometer did not reveal any flagellates, so that their concentration must have been very low, despite the high organic matter content. A few larvae of lamellibranchs were found.

(c) Swartvlei River or Sedgfield Lagoon.

Somewhat further west we find the Sedgfield Lagoon, which receives several rivers from the Outeniqua mountains and discharges into the sea

(see Plate X). The Lagoon is in open communication with the sea for part of the year only, so that water of high salinity pours in with the flood. At other times there is a sandbar across the mouth of the lagoon, which bar may break through after heavy rains in the mountains. This leads to strong fluctuations in salinity, detrimental to the well-being of oysters. The bottom we inspected was hard and sandy, covered by eelgrass and other vegetation, not suited to the planting of oysters. I therefore would not suggest carrying out any oyster experiments in Sedgefield Lagoon. Analysis of a sample of water yielded the following figures:

Station.....	Sedgefield Lagoon, southern section.	
Date.....	18/2/1953	
Temperature.....	28.3°C.	
Salinity: 50 cm. under surface	27.7‰	
P. mg. atom/m ³ : 50 cm. under surface.....	0.52	
Pigment: Filter 366.....	430mμ 6.44	670mμ 27.6
Organic matter (mg. KMnO ₄ /l).....	12.8	

A tow with a 70 μ plankton net yielded a very rich phytoplankton in which the diatom *Biddulphia* predominated. This tallies with the green colour of the water and the very high pigment value tabulated above. Zooplankton was very scarce, but I found two young larvae of an *Ostrea* oyster. As the bar was closed at the time of our observations, some adult oysters must live inside the lagoon.

(d) Rondevlei.

Rondevlei is a rather small and shallow landlocked body of water with a bottom of fine sand with patchy plant growth, mainly of *Characea* and *Zanichellia*-like phanerogamous plants. Its salinity is much lower than that of the sea, but rather constant as little river water flows into this lake. The salinity is probably too low for oysters. At most, Portuguese oysters could survive here, though it must be expected that they would develop thin and brittle shells in these stagnant and brackish waters. A small lamellibranch, *Modiola capensis*, abounded in Rondevlei.

The pigment content is rather high for the clear water of Rondevlei, though considerably lower than that for the greenish-turbid water of Sedgefield Lagoon. The very high organic matter content, as compared with that of other bodies of water is certainly conspicuous. As the water is clear and

free from pollution, one wonders what can be the reason for this high content. Could it be that the *Chara* vegetation—also observed in Groenvlei with a similar high organic matter figure—is either responsible for producing a type of organic matter not readily broken down by bacteria, or for suppressing to some extent the normal bacterial activities?

Details of a water sample I collected in Rondevlei are as follows:

Station.....	Rondevlei, centre.	
Date.....	25/2/1954	
Temperature.....	Surface. 26.3°C.	Bottom. 26.0°C.
Salinity.....	Surface. 17.0‰	Bottom. 17.0‰
P. mg. atom/m ³	Surface. 0.35	Bottom. 0.49
Pigment: Filter No. 366.....	430mμ 2.0	670mμ 7.6
Organic matter (mg. KMnO ₄ /l).....	Surface. 70.4	Bottom. 65.8

A tow with the 70 μ plankton net yielded thousands of larvae of *Modiola capensis*, which apparently thrive here. Larger phytoplanktonic organisms were extremely scarce, but small nannoplanktonic flagellates abounded (about 250,000 per cc.). Apparently these small flagellates account for the high pigment figure and served as food for the numerous larvae of *Modiola capensis*.

(e) Langvlei.

Langvlei is a body of water similar in character to Sedgefield Lagoon, and situated still farther west. We did not carry out any investigations there, but consider it unsuitable for oyster farming because several rivers discharge into it, and also because it is alternatively open and closed to the sea, and therefore will presumably show great seasonal changes in salinity.

(f) Breede River.

On March 7th, 1953, we paid a short visit to the estuary of the Breede River, situated about 40 miles south east of Swellendam. There is a wide estuary penetrating far into the land and in open communication with the sea. At the mouth a complicated pattern of sand bars forces the water to follow a sinusoidal course. In the estuary the river water mixes thoroughly with ocean water, so that a fairly high salinity is maintained. The places we visited at low tide are not suitable for the planting of oysters, but it could be that hard and stable bottom exists higher up in the nearly 16

miles long estuary. We found that the position of the downriver section of the estuary was such that it provides little shelter when the frequent south-easterly winds of summer blow. Off the little port near the Oysterbeds Hotel we measured at the surface 24.0°C . and $29.2^{\circ}/_{00}$ salinity, near the bottom likewise 24.0°C . and $29.2^{\circ}/_{00}$. Near the southern bank of the estuary, opposite the Oysterbeds Hotel, we measured 23.8°C . and $29.7^{\circ}/_{00}$ at the surface. On a trip from this point towards the mouth of the estuary the measurements were 23.1°C . and $32.5^{\circ}/_{00}$, 23.0°C . and $31.8^{\circ}/_{00}$ and 22.4°C . and $33.0^{\circ}/_{00}$, all in the surface layers, and at the last-mentioned station 22.3°C . and $33.6^{\circ}/_{00}$ near the bottom. The next morning at the Malagas ferry we found completely fresh water both at the surface and near the bottom. According to the ferryman the saline waters never penetrate as far as Malagas, but at spring tides saline waters and marine fishes are to be found only a few miles downstream.

A plankton tow in the Breede River opposite the Oysterbeds Hotel yielded a rather rich plankton with numerous diatoms, gastropod larvae and many small crustaceans, predominantly Harpacticids. I did not find any oyster larvae, however.

(g) Saldanha Bay.

Saldanha Bay is situated on the West coast some 60 nautical miles north of Cape Town (Table Bay). From the time that oyster-culture experiments were started at Knysna it was considered that Saldanha Bay might offer excellent conditions for this purpose. Certainly the occurrence of immense quantities of old oyster shells (*Ostrea atherstonei*) in the bottom deposits of the bay, and the known fact that the waters of South Africa's west coast are very rich in plankton, were suggestive in this respect.

The first experimental plantings of oysters (*Crassostrea margaritacea*, old specimens taken from the rocks on the South coast) were rather haphazard. No suitable boats were available at that time to select a good type of bottom. Part of the planted oysters were suffocated by moving sand. From a small planting north of Churchhaven, two specimens, partly submerged in sand and therefore not growing under ideal conditions, were recovered at the time of our visit. Still, the shells had put on growth and the edible parts appeared to be in reasonably good condition.

A better experiment, carried out on trays near Langebaan, has been discussed in a previous section. Of the oysters kept there in a well-sheltered site *Ostrea edulis*, *Ostrea atherstonei* and *Crassostrea angulata* grew very well indeed, indicating that there certainly is sufficient food in

the blue waters of Saldanha Bay, but there is some doubt whether water temperatures are high enough in summer to make the *Crassostrea* oysters spawn naturally. If not, the Portuguese and the common South African oyster may show the adverse effect which this has on their quality.

After inspecting this experiment we made a preliminary survey of the bay. The temperature of the water in the adjacent Atlantic ocean is rather low in summer (near Jutten Island we measured 17.8°C . at the time of our visit); the water there was greyish-green in colour and extremely rich in diatoms. The south-easterly winds prevailing in summer cause a distinct upwelling along this part of the South African West coast, which brings to the surface water rich in phosphates and other nutrients, thus promoting luxuriant phytoplanktonic development, in which diatoms predominated largely at the time of our visit.

This water does not penetrate far into Saldanha Bay. In the Bay itself we observed clear blue water of a rather high temperature making a piston-like movement with the tide. Because of great differences in temperature the ocean water coming in with the flood does not readily mix with the blue lagoon water. This could easily be observed at the time of our visit. In the seaward section of the bay there will be sites where temperatures are low at about high tide (ocean water) and much higher at low tide (lagoon water). Higher up in the lagoon temperatures are more even throughout the tidal cycle, but some ocean water will always be mixed in, and no doubt contributes to the fertility of the entire system.

No appreciable amount of river water enters the bay nowadays, and therefore one may expect that evaporation will have considerable influence on the salinity of the water in the upper part of the bay, at least in the summer season. Our salinity readings, charted in Plate XXII, indicate that evaporation is indeed an important factor here. The farther we penetrate into the bay the higher the salinity. Very high figures have been measured at the upper end of the lagoon in the channels of the saltings near the Geelbek farm. The water appeared to have a salinity of about $40^{\circ}/_{00}$ here. Even if a stable well-sheltered bottom was available here, I would be very hesitant to select such sites for oyster experimenting, because of the high salinities, reaching or exceeding the limits tolerated by oysters.

Though we did not analyse any water samples here, it is moreover our impression that the saltings should be considered as a kind of trap for the nutrients in the water. Fertile layers of clay are deposited, but the water filling the channels

and inlets is presumably much poorer in food than that in the central and northern part of the lagoon. We considered digging French-style "claires" in the fertile clay of the Geelbek saltings, but the extremely high salinities of the water would make it very hazardous to start a venture here.

From trips with a boat in other sections of the lagoon we did not get the impression that conditions are anywhere suitable for oysters.

Only part of the bottom of Saldanha Bay could be inspected at low tide; some other parts were inspected superficially by probing with poles. Our general impression is that most of the bottom consists of sand, often rather coarse sand. Practically everywhere this sand is honeycombed by burrowing organisms (*Callianassa kraussi* Stebb.). Moreover, the prevailing winds (S.E.) sweep the full length of the bay, so that very little protection can be found for shellfish to be planted in the lagoon. We explored Riet Bay in its full length at low tide. Though somewhat better protected, we found no firm soil suitable for oyster planting, but coarser and finer sands full of burrows of *Callianassa*. We would not advise planting any oysters on these grounds.

It may be interesting to record the figures of analysis of some water samples collected in Saldanha Bay:—

Station.....	Entrance of Saldanha Bay, near Jutten Island.	
Date.....	10/3/1953	
Temperature.....	17·8°C.	
Salinity.....	33·6‰	
P. mg. atom/m ³	1·41	
Pigment:	430mμ	670mμ
Filter No. 365.....	57·6	20·0
Organic matter (mg. KMnO ₄ /l).....	8·8	

These figures are typical for the rich waters of the West coast. The total phosphorus content is more than three times as high as in the Knysna Lagoon and still twice as high as in the cold water rich in phytoplankton that arrived at Knysna late in February, 1953. Pigment values are certainly high, which corresponds very well with the extreme abundance of larger diatoms we observed. Seeing so many diatoms in a sample of water we would expect a high value for organic matter too, but analysis did not confirm that. Most probably dissolved organic matter was so scarce that it

balanced the higher values for phytoplanktonic organisms. The upwelling water coming from great depths contains as a rule about 10 per cent of the dissolved organic matter present in superficial layers (ZoBell, *in litt.*), for mineralisation prevails largely over the production of organic matter in the darkness of the abyss.

Station.....	Riet Bay.	
Date.....	9/3/1953	
Temperature.....	23·0°C.	
Salinity.....	34·4‰	
P. mg. atom/m ³	1·33	
Pigment:	430mμ	670mμ
Filter No. 365.....	0·26	1·2
Filter No. 366.....	0·56	2·8
Organic matter (mg. KMnO ₄ /l).....	7·3	

The only figure differing materially from the situation at the entrance of the bay is the much lower value of pigment content. The pigment figures are of the same magnitude as observed in the warm neritic waters along the South coast. These low values correspond with the clearness of the water in Riet Bay and the scarcity of phytoplankton. As in the case of the clear blue waters of the South coast, the organic matter estimated was apparently largely in dissolved or colloidal condition, and I presume that much of the phosphorus was in organic form, temporarily inaccessible to the phytoplankton.

A sample taken in the central part of Saldanha Bay yielded figures very comparable with those from Riet Bay:—

Station.....	Central part of Saldanha Bay, in channel off Churchhaven.	
Temperature.....	21·7°C.	
Salinity.....	26·7‰	
P. mg. atom/m ³	1·30	
Pigment:	430mμ	670mμ
Filter No. 365.....	0·12	0·4
Filter No. 366.....	0·40	1·2
Organic matter (mg. KMnO ₄ /l).....	8·1	

As there are no extensive eelgrass fields and tidal mud flats in the central and northern part of Saldanha Bay, the metabolic processes will be

noticeably different there from those in the Knysna Lagoon, at least in quantitative respect.

Our samples should only be considered as preliminary data, and much more work should be carried out before the entire complicated picture of the fertility of the system and the influence of the ocean on it will be clear.

15.—RECOMMENDATIONS.

- (1) Spat collection with the aid of lime-coated tiles should be continued. In this connection Featherbed Bay in the downriver section of the lagoon is the most suitable site (see Plate XIX, Fig. 2), because of its eddies and proximity to the sea.
- (2) The area above the Knysna railway bridge should be considered as unsuitable for oyster larvae and for the settling of spat.
- (3) An increase in the numbers of spat per tile should be attempted by means of improvements in the way the tiles are placed (orientation of the rows, distances between the rows and tiles and the angle at which the tiles are placed).
- (4) It is advisable to try the modern Australian system of spat collection (thoroughly-dried tar-coated lath racks); this may lead to satisfactory results at Knysna.
- (5) Plankton investigations may help to find out whether or not oyster larvae ready to settle are abundant. When over 10 "mature" larvae provided with an eye-spot are found in 100 litres of water, settling prospects are good. As the larvae come from the sea, strong winds or the appearance of cold water may suddenly spoil the finest spatfall prospects.
- (6) The common South African oyster, *Crassostrea margaritacea*, thus far the most promising indigenous oyster for cultivation, settles predominantly in the period from January 15th to early in March.
- (7) The "weed-oyster", *Ostrea algoensis*, settles from December to early in January. Therefore it is of little use to place tiles in that period, unless one selects sites where the valuable red oyster, *Ostrea atherstonei*, may settle in appreciable numbers.
- (8) Shortly after settling of the spat, the tiles should be transferred to upriver sections, if possible to above the railway bridge, but should be placed in such a manner that tidal currents flow between the tiles. Thus damage by drills and smothering organisms can be greatly reduced. If many smothering organisms are found on the tiles, they should be destroyed by fresh water or by chemicals.
- (9) It is advisable to keep the young oysters on the tiles through their second summer and to detach them only then. This makes it necessary to have a double set of tiles, but it may lead to better growth and smaller losses among the young oysters.
- (10) Experimental work is still required to find out where and how the young specimens of *Crassostrea margaritacea* thus collected will grow and fatten satisfactorily. In this connection attention should be paid to the rich feeding grounds above the railway bridge. If the oysters can be induced to settle on Australian-style collectors, these should be nailed to supports in sheltered places in the central part of the Knysna Lagoon. However, stagnant waters are to be avoided.
- (11) Until cultivation of *Crassostrea margaritacea* is satisfactory and foolproof, I would advise work on a commercial scale with the Portuguese oyster, which appears to grow and fatten well in the Knysna Lagoon, and readily endures transportation by sea. Oysters of 14 to 18 months old are the hardest in transportation. The usual months for sale in France are February–March; part of the oysters could be bought in October–November so that they can profit from the entire South African summer season. Cultivation on trays is commercially possible (see Plate XXI, Fig. 2), provided sufficient timber and wire netting for making these are always in stock. On an experimental scale planting of Portuguese oysters directly on the bottom could be practised, especially in the area above the railway bridge. Perhaps other suitable areas could be found. Cementing oysters on tiles or laths, which should next be placed in the food-laden currents, should also be carried out on an experimental scale.
- (12) In any experiments directly on the bottom, attention should be paid to improving bottom conditions by dredging, by scattering sand or gravel, by chemical destruction of prawns and observing how long it takes for such an area to re-settle with prawns. Copper sulphate or DDT-emulsion might be good things to try here. Wire-netting or stakes should always provide protection against musselcrackers.
- (13) The "claire" is no success as it holds no water. The idea of a "claire" is to construct a pond in clay bottom, so that the fertility of the clay itself, where necessary supplemented with fertilizer (e.g. superphosphate or other phosphorus-containing products), provides

for the production of adequate planktonic food. The water should be stagnant and rather deep (over 2½ feet). Only at spring tides should new water enter to supplement the nutrients and to balance the salinity of the water. Only a limited number of oysters can be grown in these "claires", and only where thick layers of clay, impermeable to sea-water, occur, can these "claires" be constructed with success.

- (14) The "kampie" hardened with sand and gravel, and surrounded by wire seems favourable, the bottom being hard and stable enough and protection against musselcrackers being perfect. Still, growth of the oysters is unsatisfactory here. Perhaps too little green water from the mixing area comes in here and probably many feeding hours are lost at this site due to rough weather and sand particles suspended in the water hindering the oysters. A similar "kampie" constructed in a "vlei" above the railway bridge might yield better results.
- (15) The same holds good for the "dam" constructed close to the "kampie". The water flows over it for relatively few hours a day and then only the blue ocean water and very little of the richer green water coming down from the mixing area at ebb tide. Rough weather and sand may hinder the growth of the oysters here to an appreciable extent.
- (16) The newly-constructed basin on Thesen's Island, through which water passes constantly on its way to the power plant, is excellent and may serve several purposes (see Plate XXIII, Fig. 1). A good flow of water is maintained without extra expense. As soon as a double pipeline is available for alternative use, no food will be taken out of the water through filtering activities by mussels and other organisms living inside the pipeline. This oyster basin is especially good for stocking marketable oysters and for cleaning them before despatch. One could also place therein out of reach of their enemies oysters taken recently from the tiles, to heal any possible wounds sustained. Though oysters will grow in this basin, large numbers would not get enough food. Too dense a concentration of oysters may also lead to excessive development of some of their enemies.
- (17) The basin on Thesen's Island will not serve to collect spat of Portuguese oysters placed in it, since the larvae swim around for several weeks before settling down, and the current maintained would wash them out long before

then. Stagnant water in a shallow basin has never led to good results in pond culture, so that there cannot be much hope of obtaining spat of Portuguese oysters in a basin of this type.

Portuguese oysters, when grown anywhere in large numbers, might produce some offspring, which will settle down in any place, provided there are collectors. This could eventually lead to dense oyster beds, as happened on the French coast. Should the larvae not find conditions to their taste, then the importation of young Portuguese oysters should be continued. This should take place only if Portuguese oysters are found to be more promising in cultivation than native oysters.

- (18) As soon as the oyster trade gains ground and plans are made to step up production of oysters, it should be borne in mind that it is of the utmost importance to market only such oysters as are perfectly reliable from the hygienic point of view. Most of the oysters are eaten raw and should therefore meet the highest standards of hygiene. *One case of typhoid fever caused by eating oysters may ruin a business built up so patiently over many years.* The basin from which the despatch of wild and cultivated oysters takes place should be clean and protected against pollution. It should be fenced in so that no trespassers, cattle or donkeys, can come in to deposit faeces and other unwanted and dangerous materials. It should be made impossible for any contaminating material from lavatories to reach the oyster pond. Urination and defaecation on the ground surrounding the pond should be strictly forbidden. It is advisable that an experienced bacteriologist investigate the water flowing into the basin at the different stages of the tide, to find out whether or not this water meets the standards of cleanliness used for shellfish in Europe (no thermo-tolerant coli in 0.1 cc. water). I am sure that the high tide water will be found perfectly clean, and probably the low tide water as well. If not, measures should be taken to divert the low tide water directly to the power plant without first passing through the oyster pond. This will be cheaper and easier than chlorination of the water as practised in England and the U.S.A. in places where no reliable water is available.
- (19) The oysters cultivated should be properly protected against theft (see Plate XXIII, Fig. 2). Unfortunately this appears to be

necessary anywhere in the world. Van Dort has already had most unpleasant experiences in this respect: tiles have been taken out of the water to be used as roofing for a henhouse; trays have been broken open out of curiosity and carelessly left open; oysters have frequently been stolen from the trays, in which the empty shells were often left behind. Many valuable experiments thus came to an untimely end. All this is not only discouraging but it means also considerable loss, since the thieves generally take the largest oysters. Protection can never be given by the regular police. Only someone with a boat and in a position to prosecute trespassers could give proper protection. Whenever great numbers of oysters are cultivated in one particular place, a private watchman should be close by all the time, but in addition the Government should provide for some type of police patrol on the water.

- (20) As soon as the production of cultivated oysters and the sale of wild oysters increase, the organisation of the oyster company should be improved. It would save much trouble and expense if materials like wire netting for trays, coal-tar for the protection of trays and tiles are always in stock, so that no valuable trays get lost through postponing the interchanging of trays. A small 1-ton truck will avoid much trouble in transporting wild oysters and despatching marketable oysters. A young European assistant, acquainted with oysters, engines, cars and transportation, will soon be indispensable, since too much of Van Dort's time is required now by all the little things, thus leaving important things undone. A good packing shed should be available at the oyster pond.
- (21) Other bays and inlets in the Knysna area are less promising for oyster cultivation than the Knysna Lagoon itself. As this conclusion is based on preliminary observations only, it could be interesting to experiment elsewhere on a small scale, if time allows, e.g. in the Keurboom Lagoon, and perhaps also in the well-sheltered downriver section of the Sedgefield Lagoon, though it would be better to observe first what happens there when the rivers bring down much water.
- (22) Though the waters along the West coast of the Union are very rich in plankton, because of the upwelling of water from great depths the central and southern parts of Saldanha Bay do not convey the impression of being better suited to the rearing of oysters than the central part of the Knysna Lagoon.

Bottom conditions and shelter are certainly less suitable in Saldanha Bay than in the Knysna Lagoon. In the southernmost part of Saldanha Bay summer salinities may reach levels which prohibit oyster cultivation. In the northernmost section water temperatures may not rise high enough to enable *Crassostrea* oysters to spawn naturally, which is inimical for their quality in the subsequent colder season.

- (23) Potential oyster enemies should be watched closely, and measures should be taken if any of them threaten to inflict serious damage.

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PLATE I



FIG. 1.—Spat of *Crassostrea margaritacea* settled on tile collector placed in the Knysna Lagoon in the pioneering phase of the venture, 1947.

[Photo: F. W. Newdigate.]



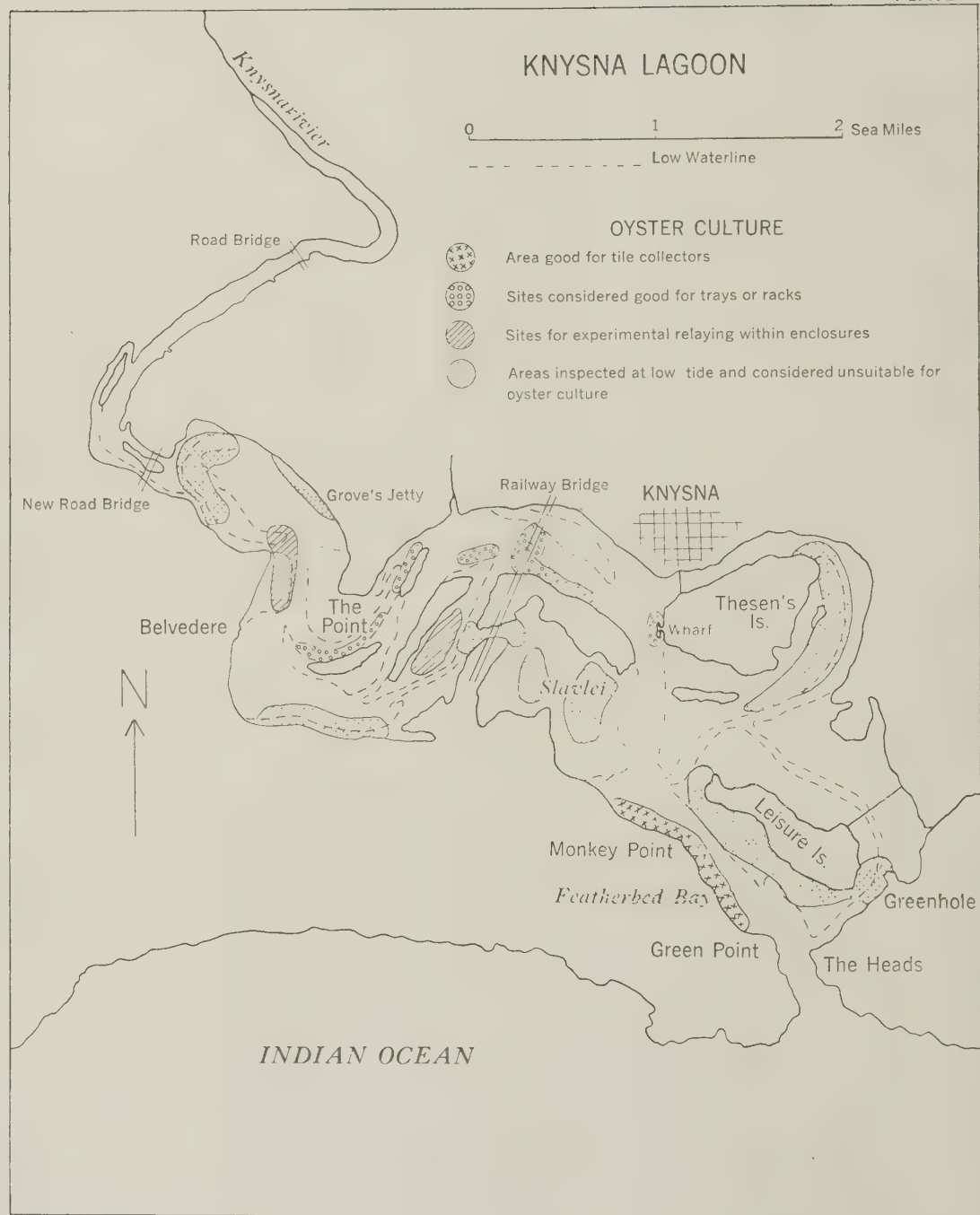
FIG. 2.—Tile collector measuring 24 ins. $\times$ 18 ins., put out end of December, 1949, and bearing about 300 young oysters, predominantly *Ostrea algoensis*.

[Photo: H. G. Bright.]

PLATE II



The Musselcracker [*Sparodon durbanensis* (Castelnau)].
[After Smith, 1949.]



Trigsurvey, 1955.

Government Printer, 1955.

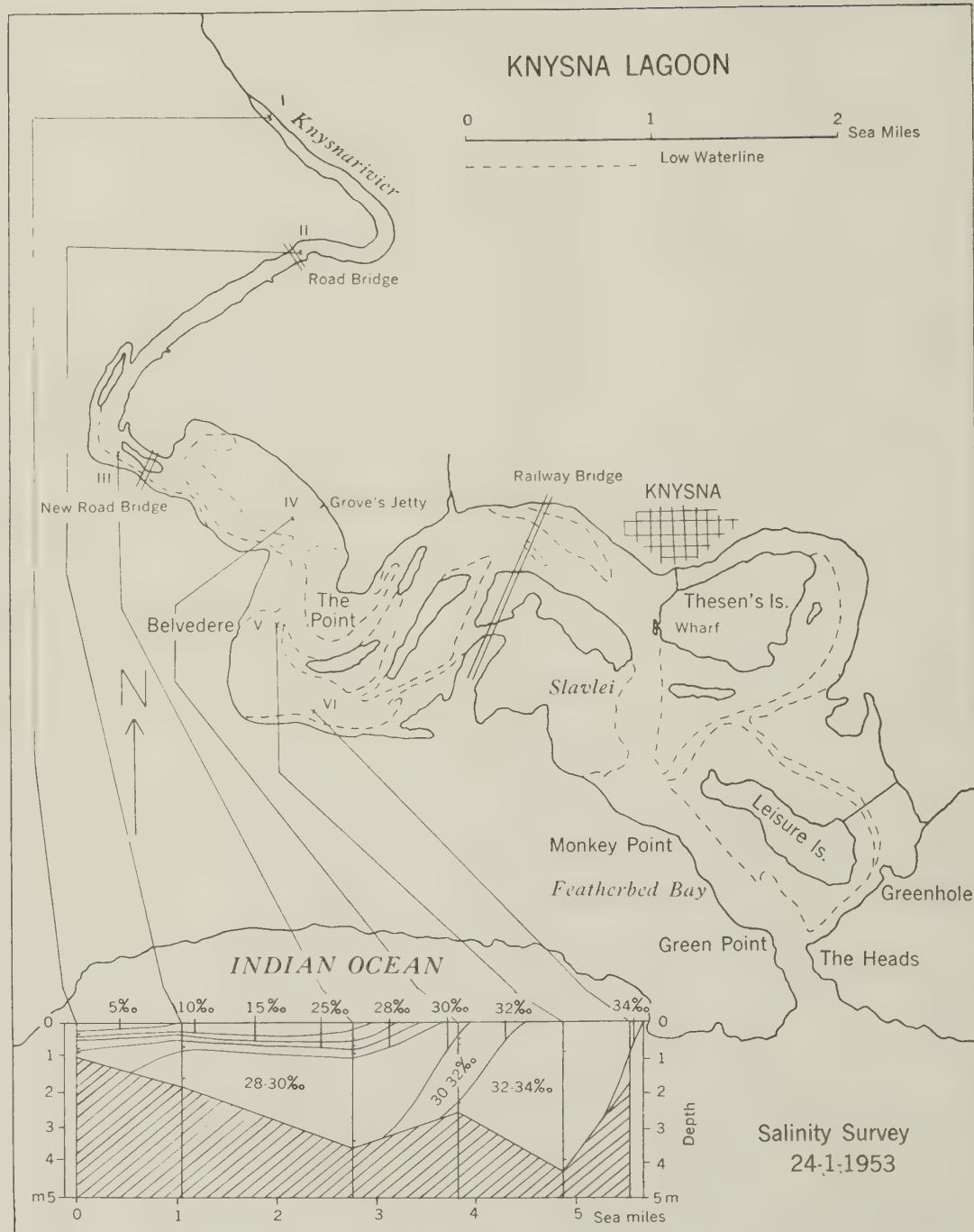
PLATE IV



FIG. 1.—*Upogebia africana*, the prawn or kapper, which honeycombs with its burrows many bottoms which might otherwise be suitable for the planting of oysters.
[Photo: P. Korringa.]



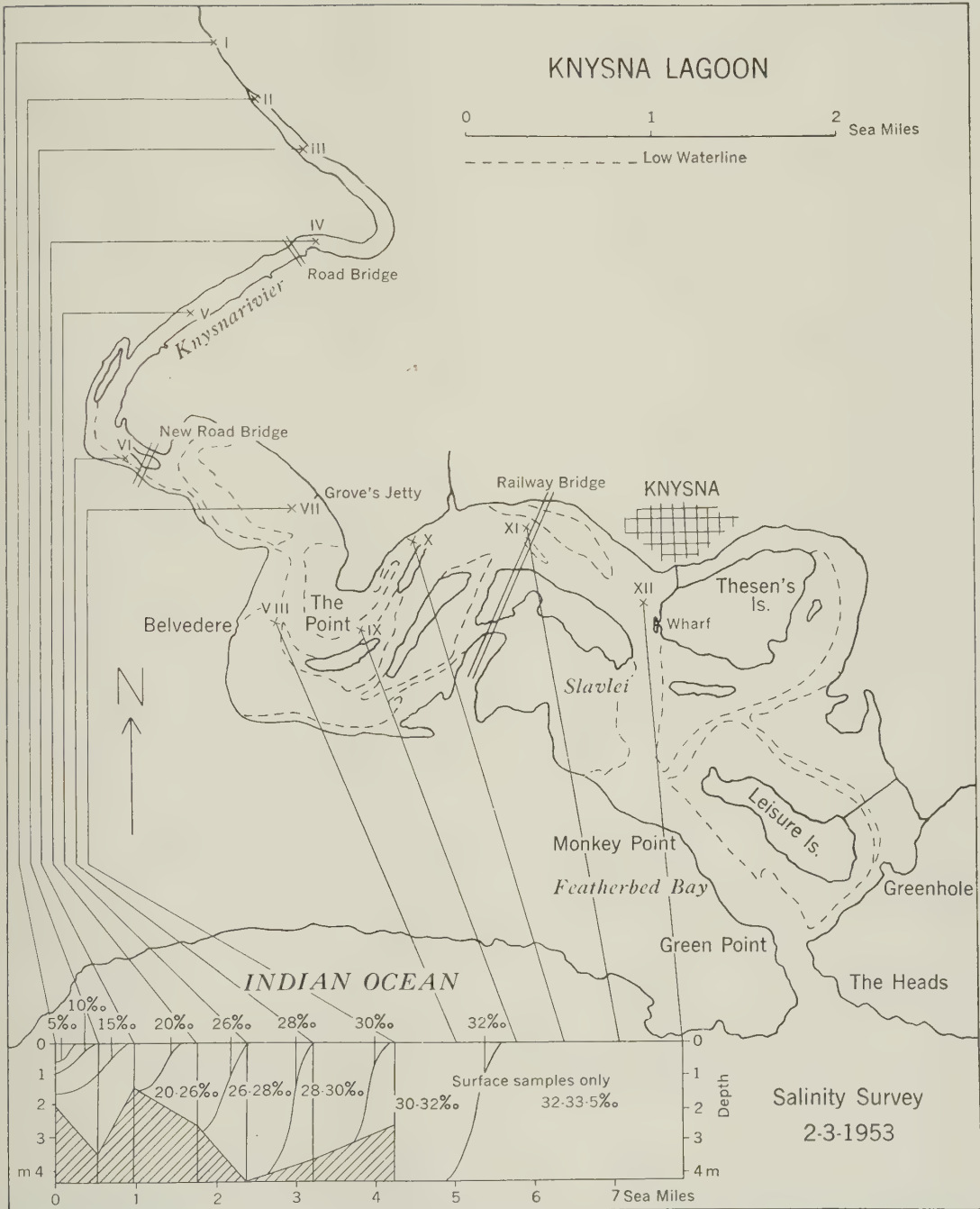
FIG. 2.—A tray with oysters in the Slavlei enclosure, well protected against musselcrackers. Mr. W. van Dort and his boy Kolberg, 1949.
[Photo: H. G. Bright.]



Trigsurvey, 1955.

Government Printer, 1955

PLATE VI





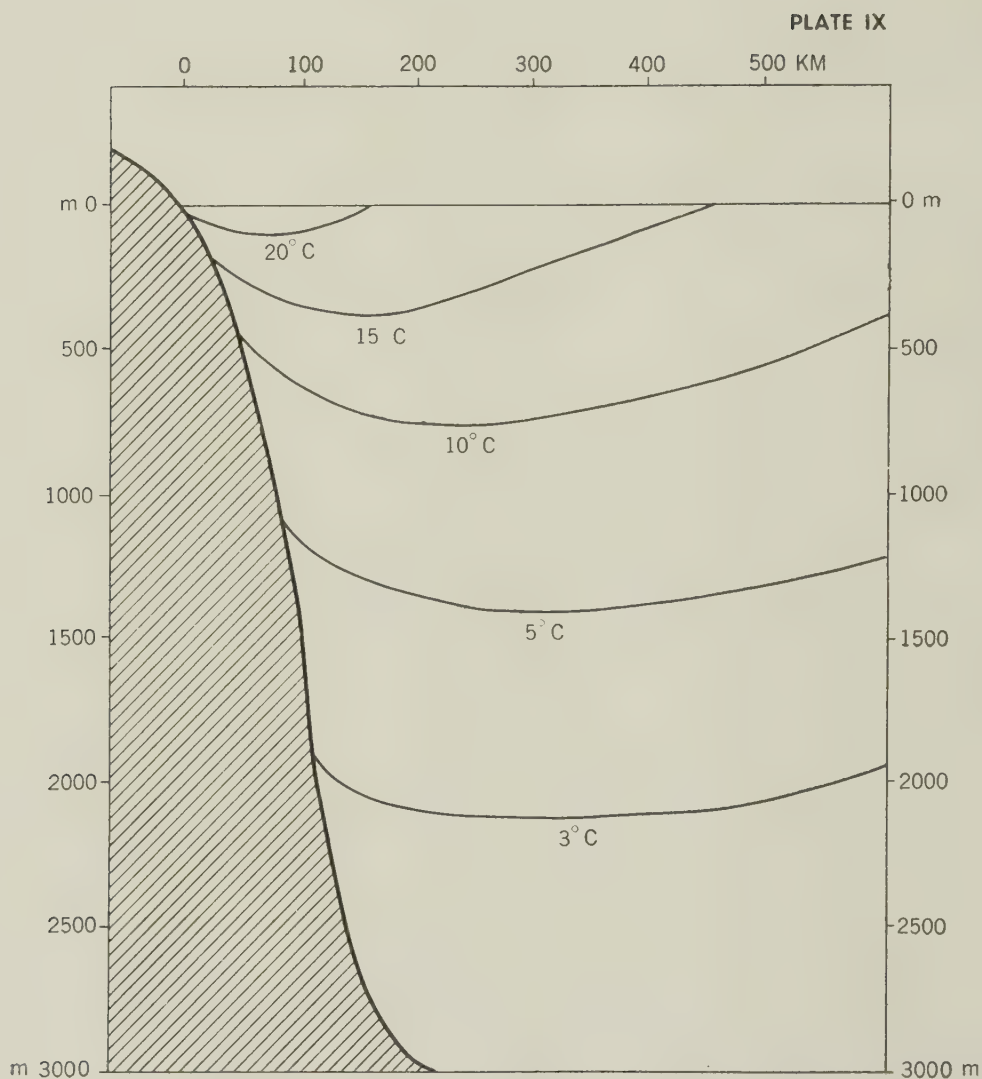
Trigsurvey, 1955.

Government Printer, 1955.



Trigsurvey, 1955.

Government Printer, 1955.



WATER TEMPERATURES ALONG THE SOUTH COAST OF AFRICA

SEMI-DIAGRAMMATICALLY AFTER DIETRICH

Trigsurvey, 1955.

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Trigsurvey, 1955.

Government Printer, 1955

The longitudinal distribution of available phosphates in the mud and water of the George's River (Botany Bay) estuarine system (Australia).

[After Rochford, 1952.]

PLATE XII



FIG. 1.—The temporary field laboratory at Knysna for plankton studies and chemical analyses of water samples.

[Photo: P. Korrington.]



FIG. 2.—Large specimens of the common South African oyster, *Crassostrea marginata*, taken from the rocks near Knysna. The three specimens at the upper right have displaced their hinge considerably, and the specimen at the lower right approximates in shape a flat oyster of the genus *Ostrea*.

[Photo: P. Korrington.]

PLATE XIII

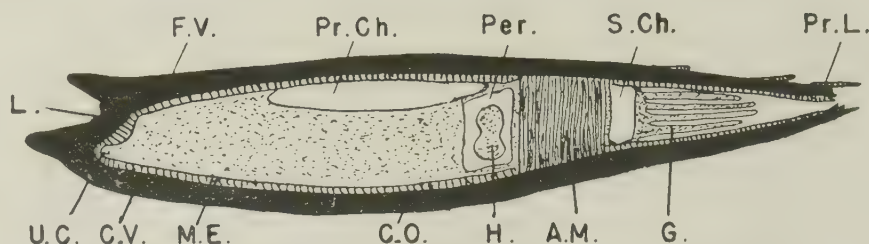


FIG. 1.—Longitudinal section of a *Crassostrea (Gryphaea)* oyster (oviparous oyster). Typical is the presence of a promyal chamber, the narrow suprabranchial chamber, the excentrical adductor muscle, the presence of an oral cavity and the scarcity of chalky deposits under the suprabranchial chamber.

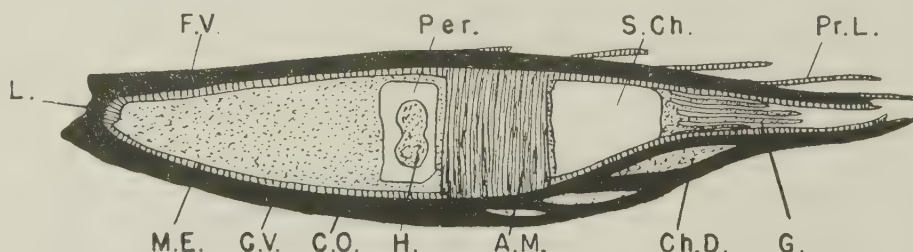


FIG. 2.—Longitudinal section of an *Ostrea* oyster (larviparous oyster). Typical is the absence of a promyal chamber, the wide suprabranchial chamber, the central adductor muscle, the absence of an oral cavity and the copious chalky deposits under gills and suprabranchial chamber.

Abbreviations.

A.M.	adductor muscle.
Ch. D.	chalky deposits.
C.O.	calcite ostracum.
C.V.	cupped valve.
F.V.	flat valve.
G.	gills.
H.	heart.
L.	ligament.
M.E.	mantle epithelium.
Per.	pericardial cavity.
Pr. Ch.	promyal chamber.
Pr. L.	prismatic layers.
S. Ch.	superbranchial chamber.
U.C.	umbonal cavity.

PLATE XIV

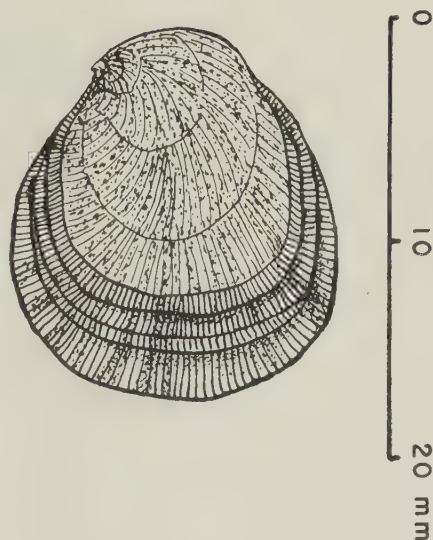


FIG. 1.—Spat of *Crassostrea* (*Gryphaea*) *margaritacea*, about one year old and measuring about 18 mm. Characteristic are the densely placed radial ribs of the prismatic layer of the flat valve.

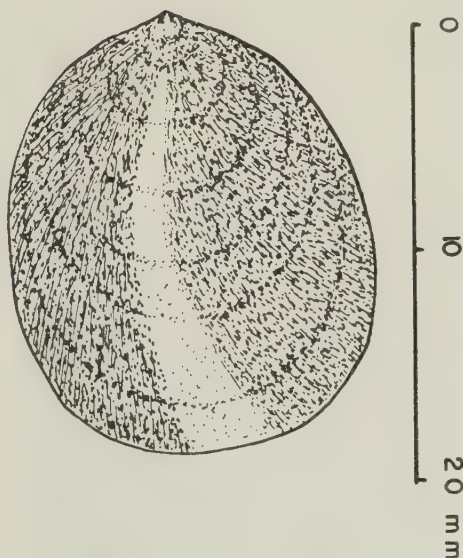


FIG. 2.—Spat of *Ostrea algoensis*, about 8 months old and measuring 20 mm. Specimen with dark pigmentation of the flat valve with exception of a yellow middle band. Structure of the flat valve's prismatic layer smooth.

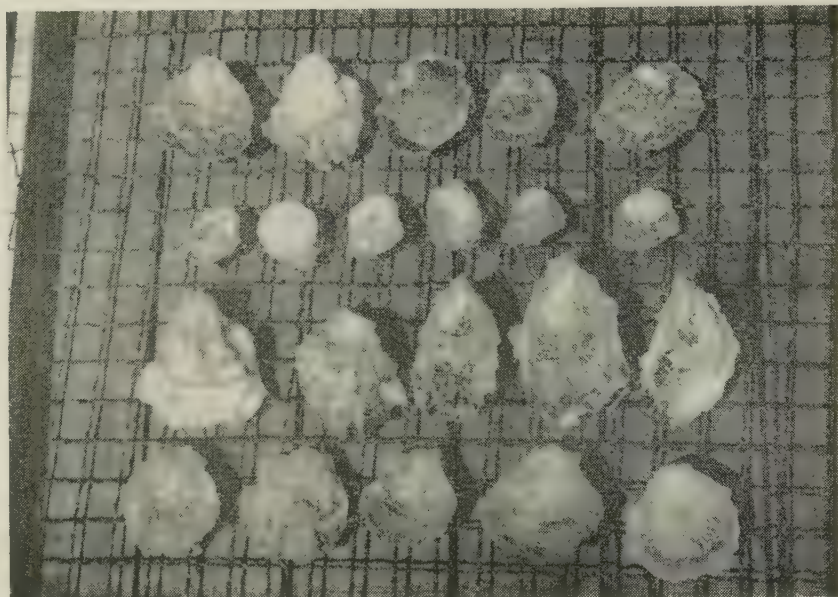


FIG. 1.—The Langebaan experiment after five months of growth.

Upper row: the red oyster, *Ostrea atherstonei*, brought in as newly-detached spat, shows excellent growth and strong shells of wine-red colour.

2nd row: The "weed-oyster", *Ostrea algoensis*, brought in as newly-detached spat, shows very little growth but is otherwise in good condition.

3rd row: Portuguese oysters, *Crassostrea angulata*, brought in as yearlings, show very good growth here.

4th row: *Ostrea edulis*, the European flat oyster, brought in from Knysna as yearlings in very poor condition, shows complete recovery and new growth shoots.

[Photo: P. Korringa.



FIG. 2.—Old shells of *Ostrea atherstonei*, the red oyster, dredged up and dried in the air by the Pearl Oyster Shell Industry at Langebaan, Saldanha Bay.

[Photo: P. Korringa.

PLATE XVI

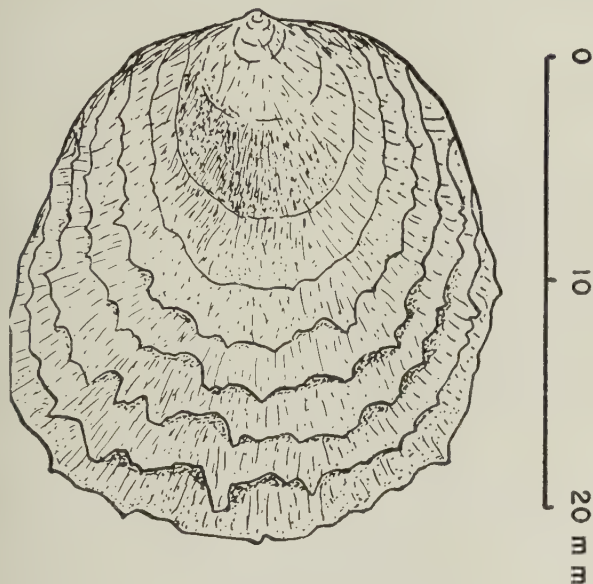


FIG. 1.—Spat of *Ostrea atherstonei* measuring about 20 mm. Prismatic layer of the flat valve with imbricated structure and of a wine-red colour. About 10 months old.

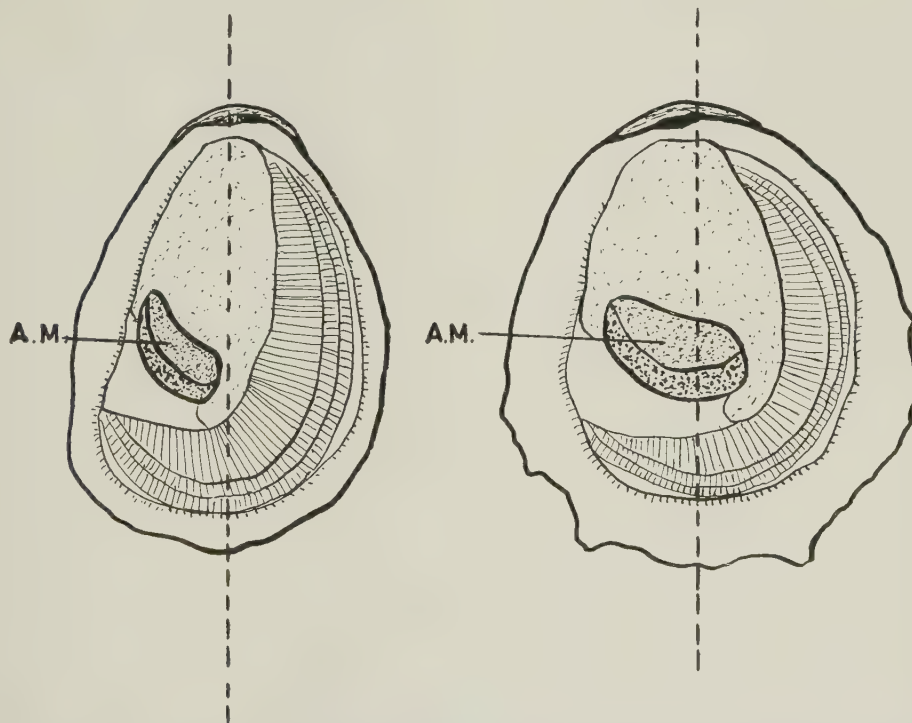
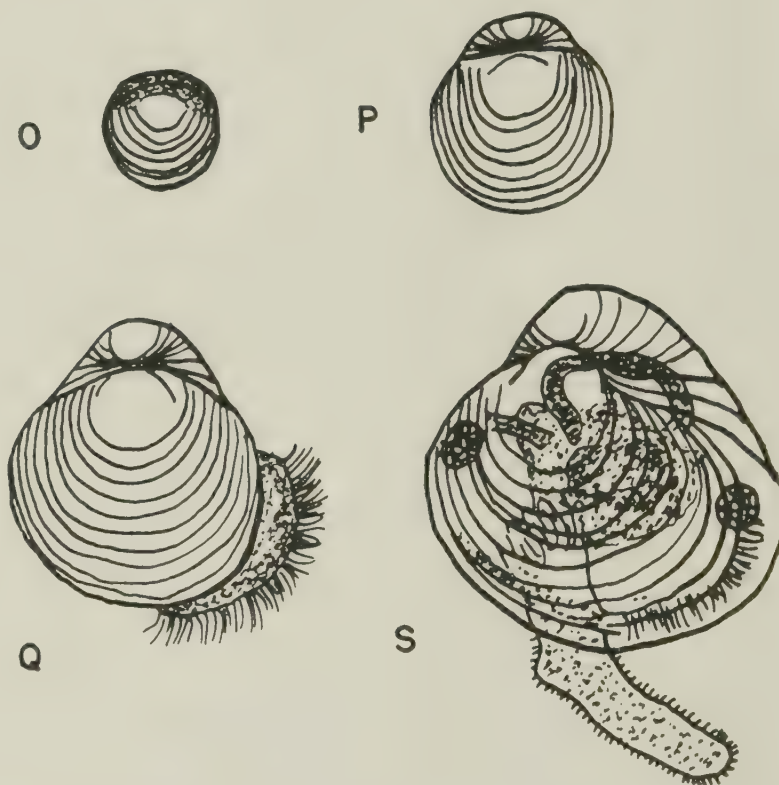


FIG. 2.—Morphological differences between specimens of *Ostrea algoensis* and *Ostrea atherstonei* of equal size (about 3½ cm.) after cutting away the flat (right) valve. At left *Ostrea algoensis* with its adductor muscle placed at the aboral side of the middle-line; the upper side of the muscle makes an angle of about 45° with the middle-line; the gills are very broad. At right *Ostrea atherstonei*: adductor muscle placed more centrally, crossed by the middle-line, and its upper side almost perpendicular to the middle-line; gills less broad than in *Ostrea algoensis*.

PLATE XVII



Larvae of *Crassostrea* (*Gryphaea gigas*) after Cahn, 1950 (original sources Icho and Oshima, 1938).

O. larva 3 to 4 days old, with development of umbo, shell about $100\ \mu$ across.

P. larva about 6 to 7 days old.

Q. larva about 8 to 9 days old, with protruding velum.

S. larva about 11 to 13 days old and ready for fixation, the shell measuring $300\ \mu$ across, the foot protruded for crawling.

PLATE XVIII



FIG. 1.—Umbo larva of *Crassostrea margaritacea* approaching settling size, and measuring $285\ \mu$ across. Left side (cupped valve) uppermost completely conceals the smaller right valve. The shell is distinctly asymmetrical.

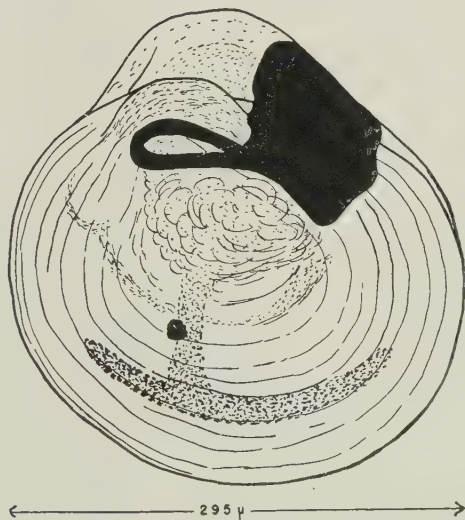


FIG. 2.—The asymmetrical larva of *Crassostrea margaritacea* ready to settle and provided with an "eye"-spot, measuring $295\ \mu$ across. Right side (flat valve) upper-most and umbo of the larger left or cupped valve protruding strikingly.

PLATE
XIX



FIG. 1.—Lime-coated tile collectors placed in rows at Featherbed Bay. Picture taken at low tide. The barge of the Knysna Oyster Company in the background.

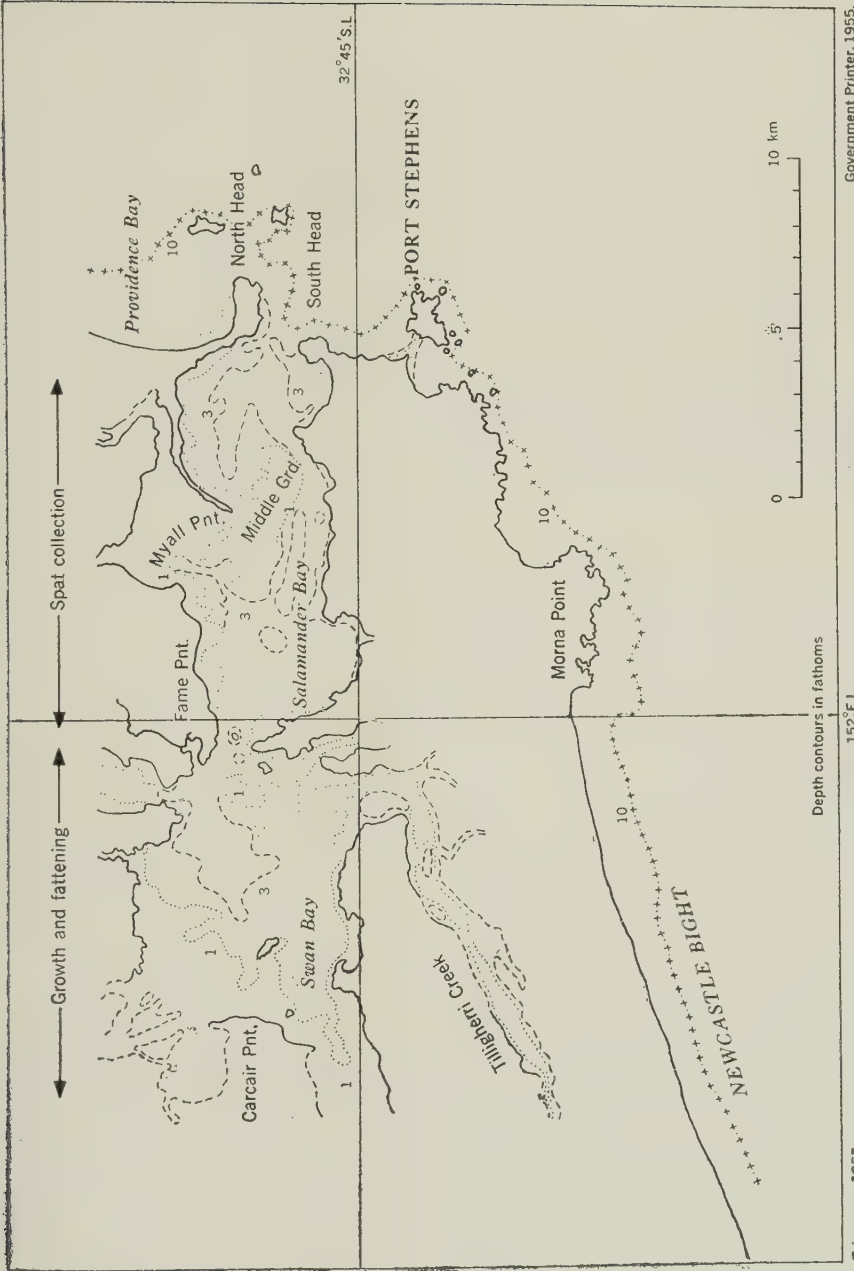
[Photo: P. Korringa.]



FIG. 2.—Oyster culture at Knysna. In the foreground tile collectors, in the background trays with oysters, protected by a row of boulders and weighted by stones. The barge carries trays for interchanging. Picture taken at Featherbed Bay at low tide.

[Photo: P. Korringa.]

PLATE XX



Government Printer, 1955.

A case strikingly parallel to that of the Knysna Lagoon. The Lagoon of Port Stephens, an important Australian oyster district. The catching leases, where the collectors are placed, are all situated along the low water line in the downriver section of the lagoon, where the clear blue ocean-water pre-dominates. Growth and fattening is concentrated on the numerous leases situated close to the low water line in the upriver section of the lagoon and its inlets, where the water is more turbid, but very rich in food.

After information provided by Mr. A. Salm, oyster farmer at Salt Ash, N.S.W.

PLATE
XXI

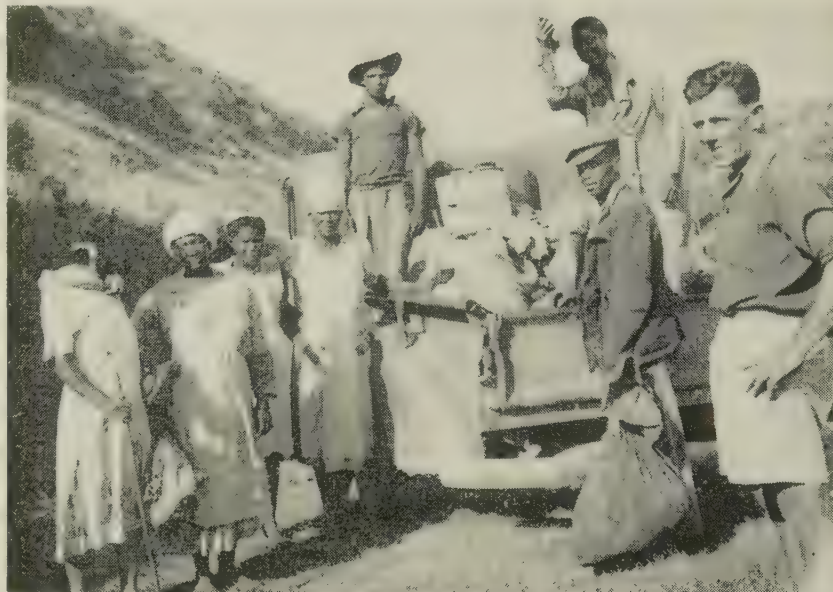


FIG. 1.—Mr. van Dort receiving a load of oysters, *Crassostrea margaritacea*, taken from the rocks near Knysna by coloured oyster pickers. [Photo: P. Korringa.



FIG. 2.—Mr. W. van Dort at an opened tray with well-grown Portuguese oysters, *Crassostrea angulata*, at Featherbed Bay.

[Photo: P. Korringa.

PLATE XXII

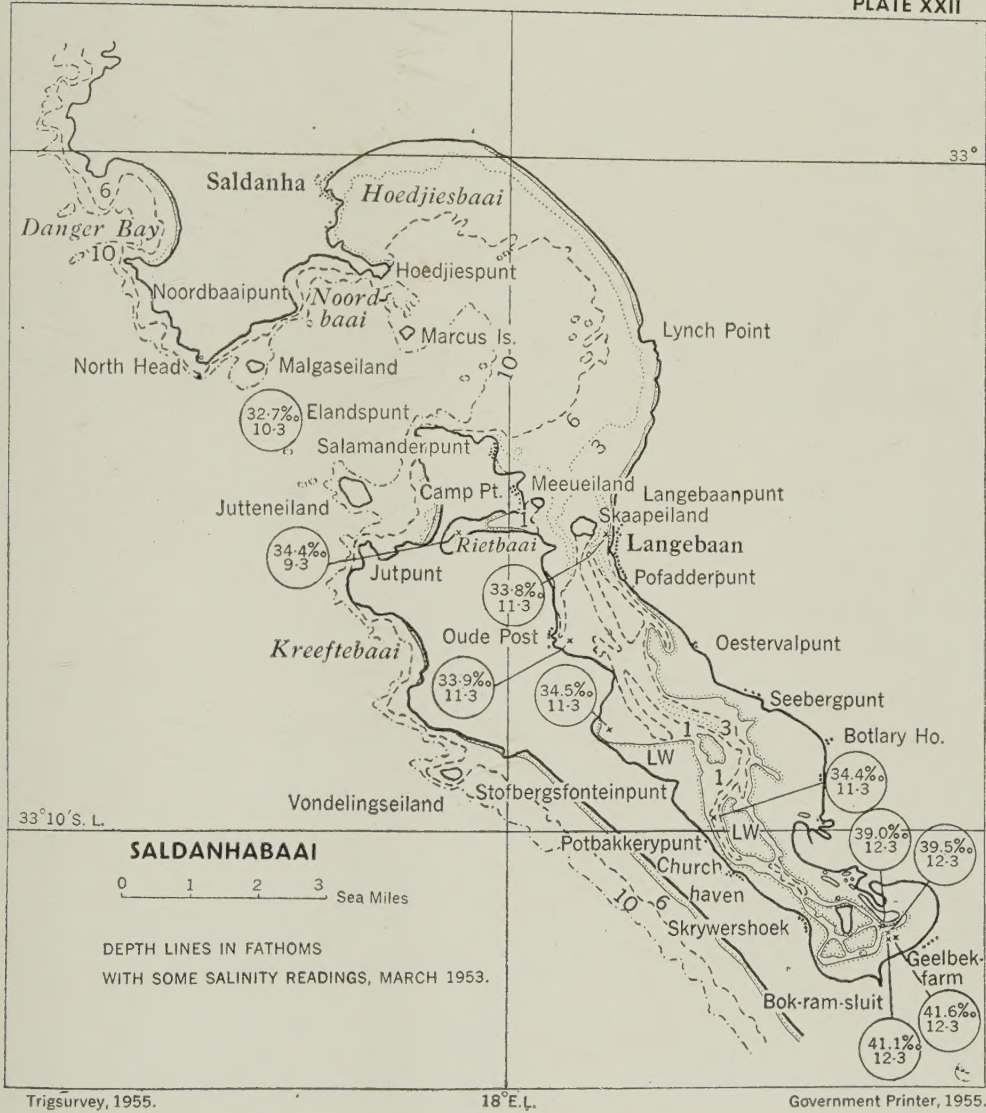


PLATE
XXIII

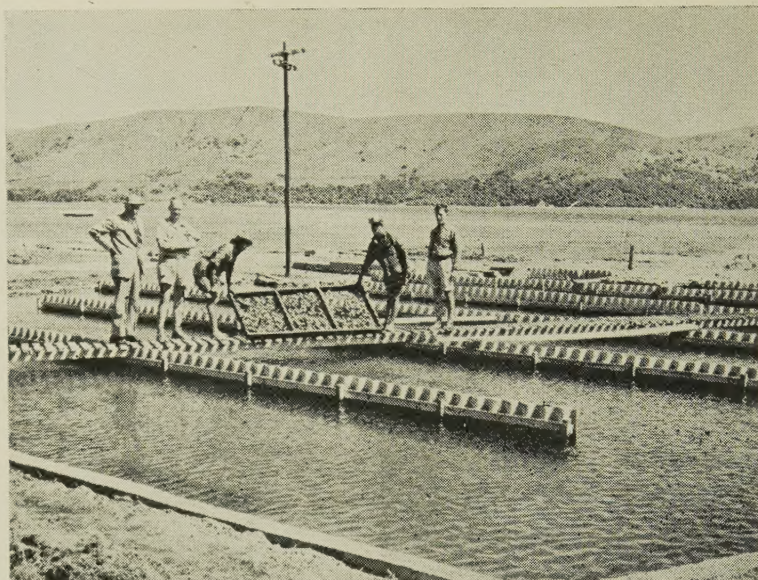


FIG. 1.—The Oyster basin of the Knysna Oyster Company on Thesen's Island. The water continually pumped in in liberal quantities follows on its way to the power plant a zig-zag course through the basin. From left to right, Mr. H. H. Thesen, Dr. P. Korringa, two boys holding a tray with oysters, and Mr. W. van Dort. March, 1953. [Photo: Reg. Jordan.]

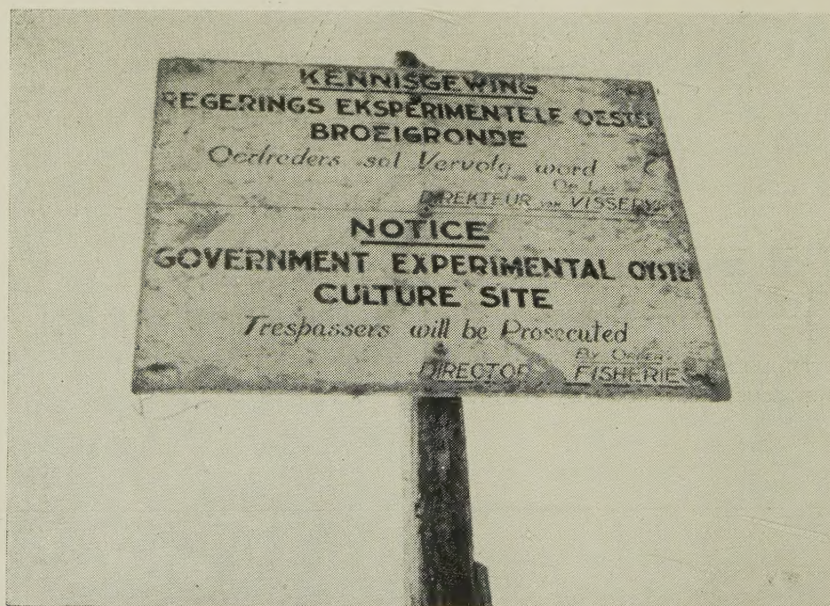


FIG. 2.—This notice at Featherbed bay appeared to be insufficient as a measure to protect the tiles and trays with oysters from unwelcome visitors. [Photo: P. Korringa.]

